NASA Contractor Report 158937

NASA-CR-158937
19790012829

Study of Future World Markets for Agricultural Aircraft

F. W. Gobetz and R. J. Assarabowski

UNITED TECHNOLOGIES RESEARCH CENTER
East Hartford, CT 06108

Contract NAS1 – 14795
April 1979

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

NASA Contractor Report 158937

Study of Future World Markets for Agricultural Aircraft

F. W. Gobetz and R. J. Assarabowski

UNITED TECHNOLOGIES RESEARCH CENTER
East Hartford, CT 06108

Contract NAS1 – 14795
April 1979

National Aeronautics and
Space Administration

Langley Research Center
Hampton Virginia 23665

The use of trade and brand names in this report does not constitute endorsement of any product.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to Mr. Dal V. Maddalon and Dr. Bruce J. Holmes of the NASA for their guidance and support in the conduct of this study. In addition, Dr. Kenneth Razak offered numerous helpful comments in his capacity as a Technical Consultant.

In the conduct of the Colombia Case study, special thanks are due Mr. Luis Fernando Gutierrez T. of AVIAGRICOLA, Dr. Elkim Bustamante of the Instituto Colombiano Agropecuario (ICA), and Mr. William R. Griebling of SANIDAD VEGETAL.

Study of Future World Markets
For Agricultural Aircraft

TABLE OF CONTENTS

Study of Future World Markets for Agricultural Aircraft

SUMMARY

This study was conducted to determine the future world market for US-manufactured agricultural aircraft and to identify the special technology needs of foreign markets if different than the requirements of the US agricultural aviation industry. Special emphasis was placed on the developing-country market, but the developed countries and the communist group were also included in the global market forecasts. Two scenarios were considered in projecting aircraft needs to the year 2000--a nominal scenario based on continuation of past trends, and an advanced scenario involving a significant shift toward aerial fertilization. In both scenarios the regional composition of the fleet was estimated in terms of required numbers of small-, medium- and large-size aircraft. The method of approach included consideration of field size, crop production, treated area, fleet productivity, and attrition in each major world market.

An operations analysis was conducted to compare the relative application costs of various existing and hypothetical future aircraft. The airplanes were evaluated over wide ranges of field size and application rate, and sensitivity studies were performed to identify important technology parameters in both the developing and developed country environments. This analysis was carried over into a case study of Colombia as a specific example of a developing country in which agricultural aviation is emerging as an important industry. The case study included a data-gathering trip to Colombia which formed the basis for analyses and projections of trends in agricultural production and aerial applications.

INTRODUCTION

The beginning of the aerial applications industry, or ag-air as it is often referred to, can be traced back to the early years of aviation (Refs. 1, 2), but its emergence as an important element of world agriculture is a relatively recent development. The rapid growth of the ag-air industry in recent years can be explained by a combination of numerous factors, but the major factors are simply the continuing need to improve crop yields and reduce labor costs. The motivation for seeking higher yields by aerial applications can be primarily economic -- as when a farmer attempts to increase his revenue through more intensive agriculture; technical -- as when rapid response to a disease or pest problem can be achieved only by air; or sociopolitical -- as when government policy prescribes an aerial program to ensure sufficient production of necessary crops. The result of these efforts is expansion of ag-air as an arm of world agriculture.

Continued growth of ag-air seems assured, although there are potential barriers which could retard its growth. Among these are problems of environmental contamination, shifting government priorities, shortages of capital, and insufficient dissemination of technical knowledge. The major impetus for continued growth is the world food problem, which persists despite significant expansion of cultivated land area and yield improvements. In the past decade, for example, world cereal yield (output/area) has increased 28 percent, and harvested cereal area increased 12 percent (Ref. 3). Population increased 21 percent during the same period, suggesting some per capita gain on a worldwide basis. However, whereas a substantial part of the cereal production increase occurred in the developed countries, almost all the population increase occurred in less-developed countries (LDCs). Thus, much of the world still falls far short of producing sufficient food grains, and the per-capita nutritional deficit continues to be about 250 cal/day in the developing countries (Ref. 4).

Recognition of the serious complications of a continuing food imbalance has prompted some basic changes in the traditional emphasis on industrialization as the primary means of economic growth for less-developed countries, or LDCs. In recent years, the need to achieve a high degree of food independence as a prerequisite for national development (Ref. 5), has gained wide support, and some reorientation of national goals and reallocation of resources has occurred. One-third of World Bank and International Development Association loans to LDCs are for agricultural development, more than double the amount for any other sector (Ref. 6). The National Academy of Sciences has called for a "major expansion of agricultural science and technology" as a first priority to "mitigate the otherwise catastrophic effects of almost inevitable crop failures" (Ref. 7).

With this background, it is clear that agricultural development, including implementation of technology, will experience increased attention in future years. Since aerial application of fungicides, insecticides, herbicides, fertilizers and seeds has been demonstrated to be beneficial for a wide variety of crops, there should be increased emphasis on ag-air as one element of the solution to the world food problem. Therefore, the NASA program to sponsor technology improvements which can make aerial applications more efficient, safer, and more cost-effective (Ref. 8) offers a direct and meaningful contribution to a serious world problem. Furthermore, since the US general aviation industry is the major supplier of ag-aircraft, NASA technology developments in this program would also benefit the US aviation community.

The domestic market has accounted for most shipments of US-manufactured ag-aircraft. Since the US ag-air industry is fairly well defined with regard to available market and agricultural data, the relevance of NASA's program to the US market can be established with some degree of assurance. For most of the world, however, the relevance of technological improvements is not clear. Accordingly, this study was undertaken to provide guidance to the program on the nature of ag-air technology requirements in foreign markets, particularly in the developing countries, where the need to make great strides in agricultural production is most pressing.

The objectives of the study have been to: 1) determine the structure of the world ag-aircraft market; 2) identify new markets which may emerge in the period between the present and the end of the century; 3) identify the required characteristics of new aircraft in order to compete in these markets and, 4) perform a case study of one developing country to obtain specific information on LDC technology needs.

AGRICULTURAL AIRCRAFT MARKETS

The initial task in this study was an analysis of the past and present world market for ag-aircraft, the objective being to gain an understanding of market structure which would serve as a starting point in making projections of future needs to the year 2000. Therefore, this section is organized in two parts; the first dealing with the historical period and the second dealing with the future.

Historical Period

Almost all aircraft used for agricultural purposes are concentrated in two countries -- the USA and the USSR -- and many countries throughout the world operate only small fleets, some of which are not even registered in the country of use. Furthermore, available data on fleet size and extent of operations (hours flown or area treated) are out of date or subject to error because of variations in census methods among developing countries. For example, multipurpose aircraft may be counted even though their agricultural utilization is minor. Also, since agricultural regions extend beyond national boundaries and ag-aviation is directly coupled to the nature of agriculture in each region, world market structure was analyzed according to the major agricultural regions of the world rather than on a country-by-country basis. The regions selected for study are listed below and shown pictorially in Fig.1.

Developed Countries

- North America (US and Canada)
- Oceania (Australia and New Zealand)
- Western Europe
- Other: Japan, Israel, South Africa

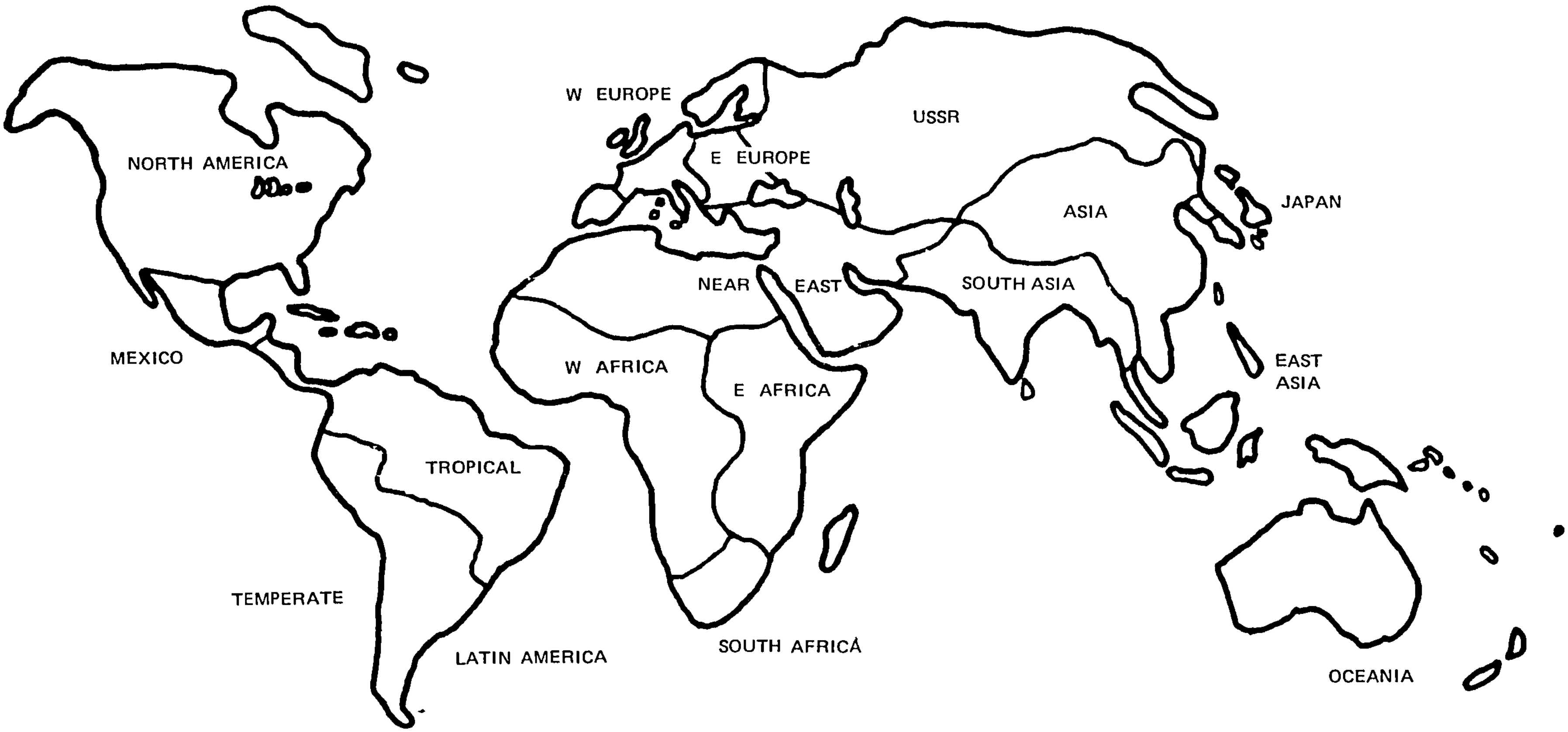
Developing Countries

- Tropical Latin America
- Temperate Latin America
- Near East
- West Africa
- East Africa
- South Asia
- East Asia
- Mexico

Communist Countries

- USSR
- Eastern Europe
- Asia

WORLD AGRICULTURAL MARKET REGIONS



79–02–29–1

FIG 1

Although this regional breakdown was used whenever possible during the study, there were instances when it became impractical to adhere strictly to the list as shown. For example, East and West Africa were sometimes grouped together because of sparsity of data on the two regions; similarly, South Asia was usually grouped with East Asia. Conversely, the US and Canada were often treated as individual countries because of the preponderance of available data pertaining to the US.

The extent of annual ag-air activity is usually expressed as either area treated or hours flown. Area treated includes multiple applications to most farms; therefore, it always exceeds farm area treated, often by a considerable amount. Adopting the most credible data available, the history of ag-air activity, in terms of annual area treated, was determined for major country groups. The results, shown in Fig. 2, demonstrate clearly that the US and the USSR account for about 60 percent of world activity and that this share has been relatively constant over the last decade. In the prior period, virtually all aerial treatment was confined to these two countries.

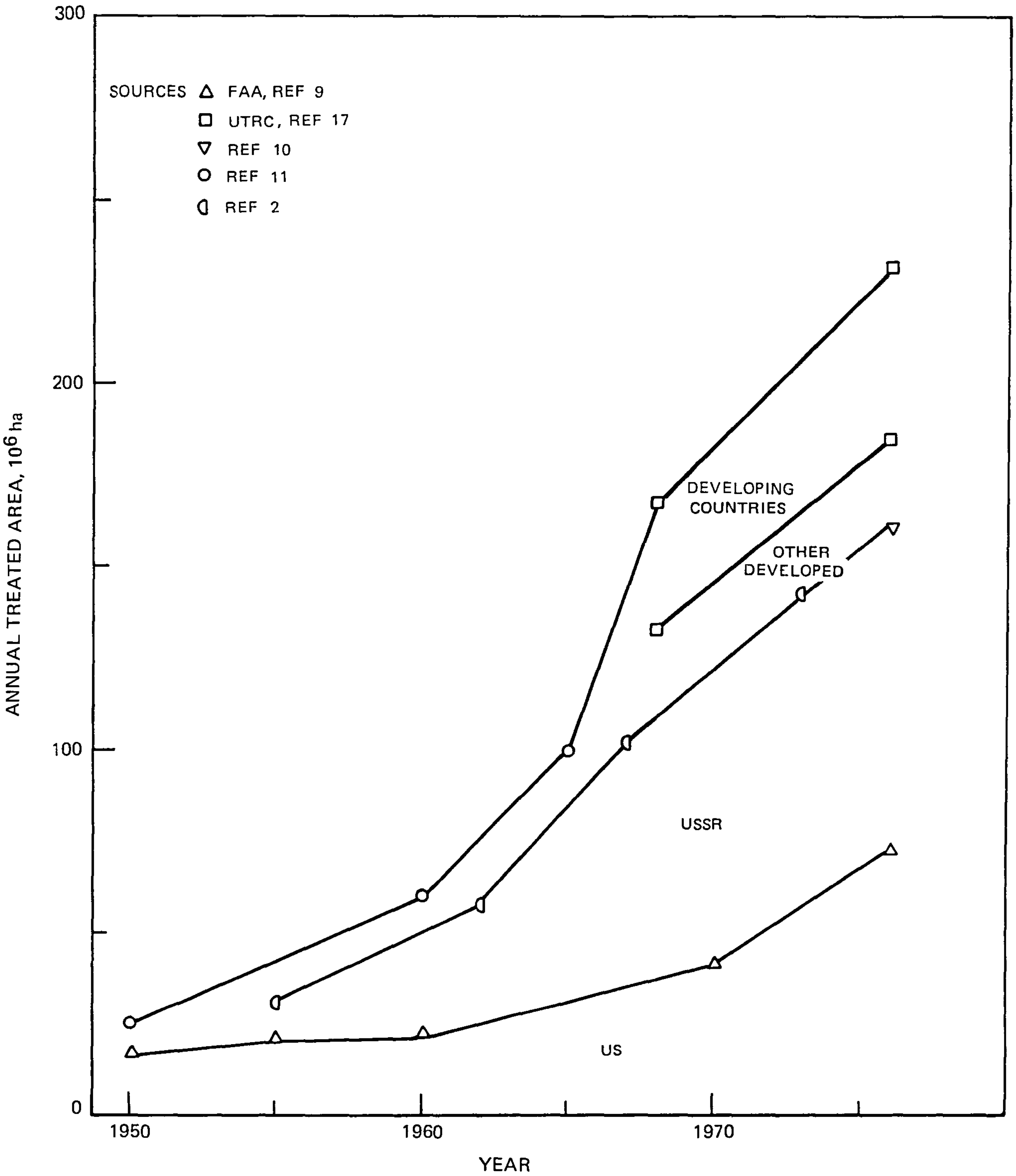
All data for the US in Fig. 2 were taken from FAA publications (Ref. 9) dating back to the 1940s. These data are by far the most credible of the sources utilized to construct the historical picture of aerial treatment over the period shown. The information for USSR aerial treatment was obtained from Ref. 2, which is a NASA translation of a recent Russian publication, and from Ref. 10, which included a survey of many countries throughout the world. The survey data from Ref. 10 were also used to show recent trends in other developed and developing nations, with adaptations made at UTRC to compensate for about a ten-year variation in the census sources. Estimates of worldwide aerial treatment for the 1950-to-1965 period were taken from Ref. 11, which is the least credible of all the sources used.

When the same sources were used (except for Ref. 11) to describe the history of the world ag-air fleet since 1950, the trends shown in Fig. 3 emerged. There are, at present, over 25,000 aircraft active in aerial treatment throughout the world although, as noted earlier, some are utilized only part-time for agriculture. The USSR's large fleet of 10,000 aircraft, for instance, consists entirely of multipurpose models which serve as transports in passenger and cargo service as well as for aerial treatment (Ref. 2).

Agricultural Airplane Characteristics

Although many airplane models are used in agricultural operations, the number of models produced specifically for agricultural use is relatively small. Moreover, not all ag-aircraft tabulated in the literature are being produced at present. Therefore, for the purposes of this study, emphasis has been placed on models designated for agricultural use by their primary manufacturers, or offered as conversions by secondary manufacturers. A

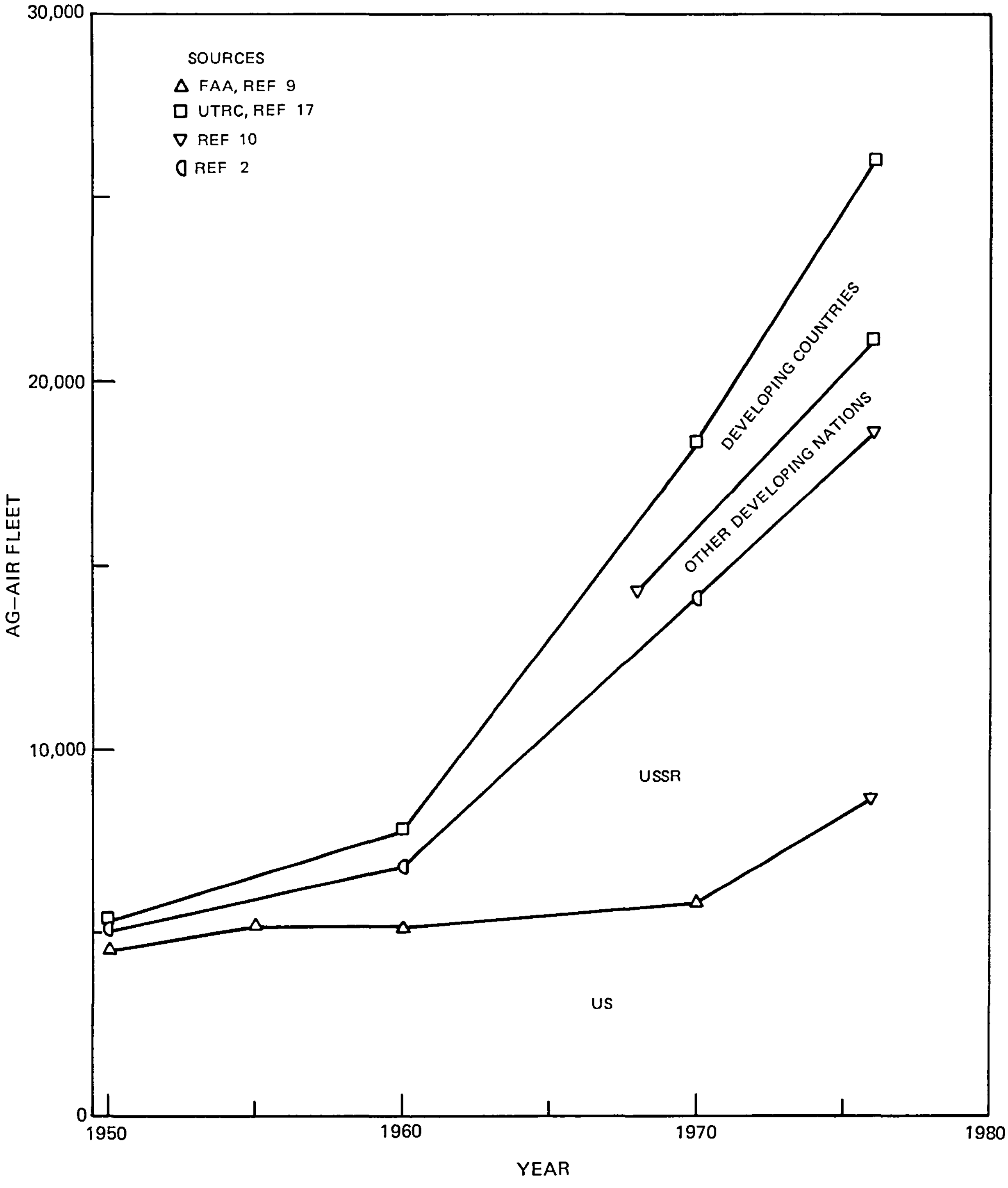
HISTORY OF WORLD AG–AIR ACTIVITY



79–01–255–3

FIG. 3

HISTORY OF WORLD AG—AIR FLEET



79—01—255—22

comprehensive listing of all such aircraft produced in the developed countries is provided in Table 1. A second list, Table 2, summarizes the models presently in production in the developing countries*. The formats of the two tables are identical.

The data presented in Tables 1 and 2 for the various airplanes fall into three categories:

1. Physical characteristics, including weights, dimensions, and power

2. Performance criteria such as range, endurance, and speeds, and

3. Economic measures, including price and operating cost.

The physical and performance data were extracted from several sources, particularly Refs. 12-14. Price information was obtained from Refs. 12 and 15, with additional entries estimated according to the price correlations in Figs. 4 and 5. These figures correlate flyaway price with airplane empty weight. A more accurate method would be to correlate airframe price (flyaway price less price of engines) with airframe weight (empty weight less weight of engines). However, because so many models are powered by used engines, for which precise costs are unavailable, that method was not employed. Operating costs were estimated by the method summarized in Table 3, which was based on Refs. 1, 16 and 17, and are included only to provide a general operating cost comparison of aircraft types by a consistent method of analysis.** Note, particularly, that airplane price enters the operating cost calculation in several places, and that only estimated prices were available for many of the aircraft in Tables 1 and 2.

Competition from Foreign Manufacturers

Represented in Tables 1 and 2 are fifteen countries, producing a total of 44 ag-aircraft models. The breakdown by sector, country, manufacturer, and model is as follows:

Sector	Countries	Manufacturers	Models
United States	1	10	22
Other Developed	6	7	9
Eastern Europe	4	4	4
Developing Countries	4	4	9
TOTAL	15	25	44

*Some aircraft in Tables 1 and 2 are proposed models which are not yet in production. Others are agricultural models of utility aircraft for which most production output is for other purposes.

**Other sources of operating costs may differ depending on the methods used for estimation and the cost elements included, particularly indirect costs such as insurance, taxes, airstrips and hangars.

TABLE 1

CHARACTERISTICS OF AGRICULTURAL AIRCRAFT

Developed Countries

Country	Airframe Manufacturer	Model Designation[1]	Eng Mfr	Engine Designation	Sea Level Power kW	Takeoff Weight kg	Empty Weight kg	Payload[3] kg	Hopper Capacity liters	Wing Span m	Wing Area m^2	Range or Endurance	Working Speed km/hr	Stall[6] Speed km/hr	Flyaway Price[2] 1978 $	Est Oper Cost[9] $/hr
France	Aerospatiale	SA 315B Lama (H)	Turbomeca	Artouste IIIB (T shaft)	419	1950	1018	1000	1135	-	-	3 33 hr	-	-	325 000	279
'	Socata	RALIYE 180 GT	Lycoming	O-360 A3A	134	1050	570	220	580	9 74	12 28	1300 km	-	92	(36 800)	61
Italy	Silvercraft	SH-200 (H)	Lycoming	LHIO-360-CIA	153	862	495	250	-	-	-	354 km	-	-	(45 000)	74
Australia	Transavia	PL-12 Airtruk	RR Cont	IO-520D	224	1855	775	-	818	11 98[4]	23 80	531 km	-	97	(44,600)	74
	"	T-320 Airtruk	Cont	Tiara 6-320-2B	242	1855	816	907	816	11 98	23 48	-	205[8]	87	(46 100)	77
New Zealand	Aero Ind	Fletcher FU 24-950	Lycoming	IO-720-A1B	298	2463	1207	1052	1045	12 81	27 31	709 km	195	91	81,475	100
"	"	Cresco		LTP-101	438	3175	1133	1531	1705	12 81	27 31	3 9 hr	225[8]	97	(159 000)	145
Switzerland	Pilatus	PC-6 Turbo Porter	P&WAC	PT6A-27	410	2770	1215	1132	1330	15 13	28 80	4 33 hr	167	70	(163,000)	144
U S A	Air Tractor	AT-301 (Snow S-2B)	P&W	R-1340	447	2994	1633	-	1218	13 72	25 08	563 km	225[7]	86	64,900	107
"	"	AT-302	Lycoming	LTP-101 (Turboprop)	447	2994	1474	-	1218	13 72	25 08	603 km	-	-	127,000	130
'	Cont. Copters	Mk V-A (B-47) (H)	Lycoming	VO-435-A1F	194	1111	623	371	-	-	-	1 5 hr	-	-	52,000	88
	"	Mk VI-B (B-47) (H)	"	TVO-435-B1A	164	1293	676	520	-	-	-	1 5 hr	-	-	62,000	85
"	Cessna	Ag Wagon A188B	Cont	IO-520-D	224	1814	987	657	757	12 41	18 80	2 6 hr	195	106	43,950	74
	"	Ag Carryall A185F	"		224	1520	865	413	571	10 92	16 20	4 1 hr	225[8]	91	49 400	77
	"	Ag Truck A188B		'	224	1905	1013	721	1060	12 68	19 04	2 6 hr	195	95	49,400	77
"	"	Ag Husky A188B	'	TSIO-520-T	231	2000	1042	783	1060	12 68	19 04	3[illegible]2 km	189	95	54 800	79
"	Eagle	400	Lycoming	IO-720	298	2369	1199	914	946	16 50	34 74	5[illegible]5 km	192	85	(60 000)	90
'	Emair	MA-1	P&W	R-1340	447	3175	1610	1247	1703	-	-	-	167	104	62,300	106
	"	MA-1B	Wright	R-1820	671	3269	1928	1360	1703	12 70[4]	37 16	-	195	117	72,500	133
"	Gulf Amer	Ag Cat G-164B	Cont	R-975	391	2756	1380	1134	1136	12 88[4]	36 42	835 km	169	96	71 410	105
	"	Ag Cat G-164C	P&W	R-1340	447	2756	1656	-	1893	10 95[4]	30 47	706 km	185	96	83,965	117
	"	Turbo Cat (Frakes Conv)	P&WAC	PT6A-34AG	559	2756	1273	1248	1136	-	-	-	178	95	187,500[5]	170
"	Hiller	UH-12E (H)	Lycoming	VO-540-C2A	254	1270	798	-	305	-	-	346 km	-	-	89 890	123
"	Hughes	300CD(H)	Lycoming	HIO-360-DIA	142	930	476	344	305	-	-	3 0 hr	-	-	69 000	83
"	"	500D (H)	Allison	250-C20B (Turboshaft)	313	1361	617	536	680	-	-	2 0 hr	-	-	210,000	195
"	Piper	PA-25D Pawnee	Lycoming	O-540-B2C5	175	1315	709	480	568	11 02	17 00	2 1 hr	139	98	38,220	66
	"	PA-36 Pawnee Brave 300	'	IO-540-K1C5	224	1769	1039	475	1041	11 80	20 90	1030 km	189	111	54 760	79
	"	PA-36 Pawnee Brave 375	"	IO-720-D1CD	280	1769	1102	357	1041	11 80	20 90	861 km	193	115	73 170	94
"	Ayres	Thrush 600	P&W	R-1340	447	3130	1678	618	1515	13 56	30 34	2 4 hr	185	106	84,900	117
	"	Thrush 800	Wright	R-1300	597	3538	1860	437	1515	13 56	30 34	1 5 hr	202	109	85,900	133
	"	Turbo Thrush	P&WAC	PT6A-34AG	559	3720	1633	748	1515	13 56	30 34	1 9 hr	148	106	184 500	169
"	Weatherly	201C	P&W	R-985	336	2177	1170	802	1022	11 89	23 35	-	176	111	54 000	91
USSR	Kamov	KA-26 (H)		M-14V-26 (Twin T shaft)	485	2980	2216	900	-	-	-	3 7 hr	-	-	(375 000)	320

(1) (H) designates helicopter
(2) 12/77 prices, ( ) are estimates
(3) Generally at maximum fuel
(4) Upper wing (biplane)
(5) Based on Gulfstream American price for new airplane
(6) Flaps down
(7) Economical cruising speed
(8) Cruising speed at 75% power
(9) Based on 500 hr/yr aircraft utilization

TABLE 2

CHARACTERISTICS OF AGRICULTURAL AIRCRAFT

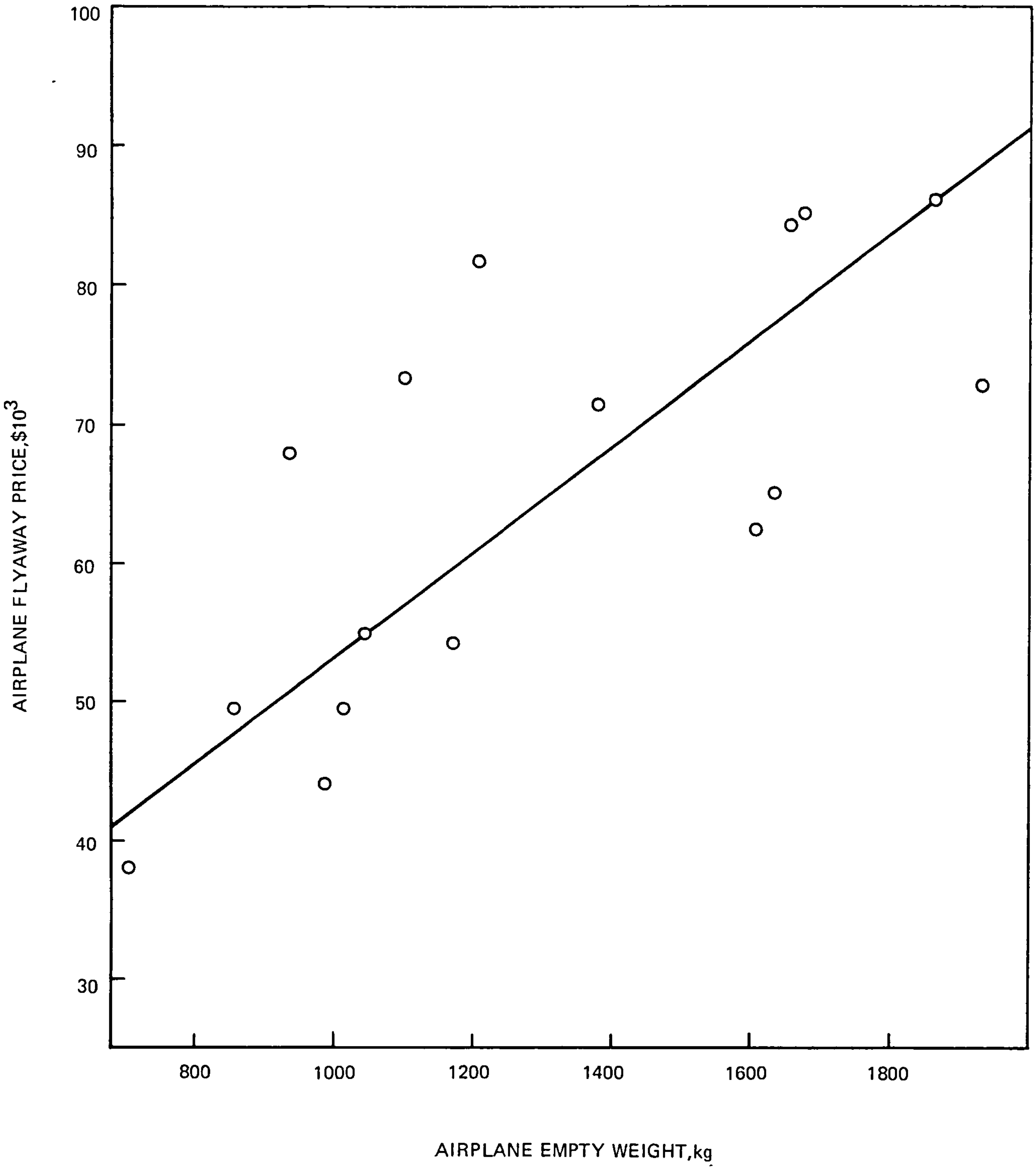
Developing Countries

Country	Airframe Manufacturer	Model Designation (1)	Eng Mfr	Engine Designation	Sea Level Power kW	Takeoff Weight kg	Empty Weight kg	Payload (3) kg	Hopper Capacity liters	Wing Span m	Wing Area m^2	Range or Endurance	Working Speed km/hr	Stall (6) Speed km/hr	Flyaway Price (2) 1978 $	Est Oper Cost (9) $/hr
Argentina	Aero Boero	260 Ag	Lycoming	O-540	194	1350	720	500	500	10 90	16 47	1100 km	175 (7)	97	(42,500)	70
Brazil	Embraer	Ipanema IMB-201A	Lycoming	IO-540-K1D5	224	1800	934	750	680	11 69	19 94	880 km	205 (8)	92	68 000	86
Czechoslovakia	Let	Cmelak Z-237	Walter	M-462 RF	235	1850	1045	600	650	12 22	23 80	640 km	120	81	(54,800)	81
India	HAL	Basant HA-31 Mk 2	Lycoming	IO-720-C1B	298	2185	1223	760	935	12 00	23 34	1 0 hr	145	91	(61,600)	90
Mexico	Anahuac	Tauro 300	Jacobs	R-755-A2M1	224	2065	960	800	870	11 45	20 24	375 km	135 (7)	89	(51 600)	78
Romania	ICA-Brasov	IAR-822	Lycoming	IO-540 C1D5	216	1900	1080	630	600	12 80	2600	3 0 hr	120-160	88	(56 100)	79
"		IAR-827		IO-720-DA1B	298	2350	1280	800	1200	14 00	29 00	2 5 hr	-	110	(63,700)	91
Yugoslavia	UTVA	Super Privredinek 350	Lycoming	IO-540-A1C	261	2010	1135	600	-	12 90	20 53	120 km	160 (7)	88	(58,200)	85
Poland	PZL-Mielec	AN-2R	Shvetsov	ASz-621R	746	5500	3450	1350	1500	18 18	71 60	900 km	185 (7)	75	110 000	160
"	PZL	Cawron PZL-101	Ivchenko	AI-14R	194	1660	1025	500	800	12 71	23 86	660 km	110-130	-	(55 900)	77
	WSK-Okecie	Kruk PZL-106	PZL	PZL-35	447	3000	1575	1000	1400	14 80	28 40	400 km	120-160	92	(74 900)	112
"	WSK-Mielec	M-15	Ivchenko	AI-25(Turbofan)	1500 kg	5650	3090	2200	2900	22 40 (4)	67 50	1 5 hr	140-165	108	3 375 000	1931
"		M-18 Dromader	Shvetsov	ASz-621R	746	4200	2470	1500	2500	17 70	40 00	520 km	170-185	109	(108,800)	160
	PZL-Swidnik	Mi-2 (H)	Isotov	GDT-350 (Twin T shaft)	591	3550	2365	700	1200	-	-	-	30-60	-	(760 000)	537

(1) (H) designates helicopter
(2) 12/77 prices ( ) are estimates
(3) Generally at maximum fuel
(4) Upper wing (biplane)
(5) Based on Gulfstream American price for new airplane
(6) Flaps down
(7) Economical cruising speed
(8) Cruising speed at 75% power
(9) Based on 500 hr/yr aircraft utilization

FIG 4

AIRPLANE PRICE CORRELATION FOR PISTON–POWERED AG AIRCRAFT

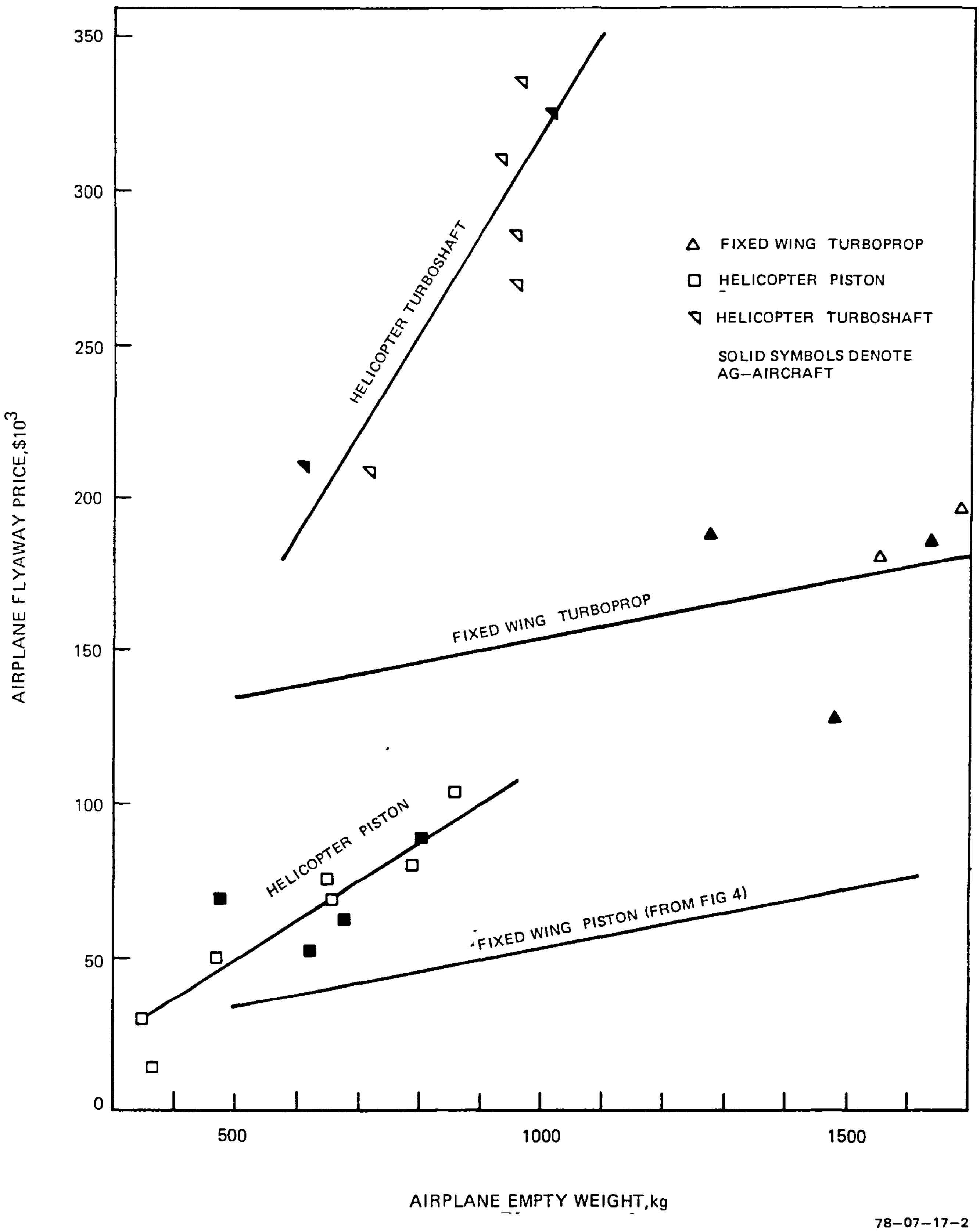


78–07–17–1

FIG. 5

AIRPLANE PRICE CORRELATIONS

SINGLE ENGINE MODELS



78–07–17–2

TABLE 3

OPERATING COST ESTIMATION

Annual (Fixed) Costs – \$/year	
Depreciation	$\frac{(1+SF)(1-SV)C_F}{T_D}$
Interest	$\frac{C_F(1+SV)}{2}\frac{I_R}{100}$
Taxes & License	$\frac{C_F(1+SV)}{2}\frac{T_R}{100}$
Hangar & Airstrip	$\frac{C_F(1+SV)}{2}\frac{F_R}{100}$
Insurance	$\frac{R_H C_F}{100} + \frac{(1+SV)}{2}\frac{C_F R_F}{100} + 2220$
Hourly (Variable) Costs – \$/hr	
Fuel & Oil	$\frac{P \cdot SFC \cdot C_G}{2\rho}$*
Maintenance & Overhaul	$(0.054 \cdot P) + 7$ Piston $(0.053 \cdot P) + 2$ Turbine $(0.210 \cdot P) - 10$ Helicopter
Crew	18

C_F = Flyaway Cost, \$

SF = Spares Factor = 0.1

SV = Salvage Val. Factor = 0.1

T_D = Depreciation Period = 10 yrs

I_R = Interest Rate = 10%/yr

T_R = Tax & License Rate = 6%/yr

F_R = Facilities Rate = 3%/yr

R_H = Hull Insurance = 3%/yr

R_F = Fire, Theft & Damage = 2.5%/yr

P = Power, kW

		Piston	Turbine
ρ = Fuel Density, kg/liter	=	0.607	0.679
SFC = Specific Fuel Cons., $\frac{kg}{hr\text{-}kW}$	=	0.304	0.347
C_G = Fuel Cost, \$/liter	=	0.193	0.163

* Factor of 2 in denominator accounts for assumption that operating power at working speed equals 1/2 rated takeoff power

In this breakdown, the Eastern European Communist countries are listed separately, although the smaller ones are grouped with the Developing Countries in Table 2; the USSR is included in the Other Developed Country category*.

Production volumes are unavailable for most models of foreign manufacture, but serious competition to US manufacturers is posed only by those countries with established (or rapidly growing) industries, and even then the US will achieve significant penetration. Although other developed countries might be expected to be important in this regard, the following data suggest that this is not the case.

Country	1976 Fleet	US Models as Percent of Fleet	Recent Shipments of US Aircraft 1975-1978
Australia	247	68	35
France	90	82	4
Italy	32	--	6
New Zealand	451	66	6
Switzerland	--	--	26
USSR	10,000	--	0
USA	8,646	~ 100	1544

Dashed line indicates no data available

For Australia, France, and New Zealand, the large percentage of US models in current fleets shows that US manufacturers penetrate these markets despite competition from domestic manufacturers. In the case of Italy, only a single helicopter is manufactured for agricultural purposes. Switzerland also has one manufacturer, Pilatus, which produces the Turboporter, a fairly large, turbine-powered model. The unusually large number of shipments to Switzerland can be explained by the fact that Switzerland is a distribution point to other European nations and the Near East. Although the USSR has a highly developed technology base, it is not active in the manufacture of agricultural aircraft, as noted above. The implications of the USSR's technological strength will affect the marketplace, however, through transfer of this capability to Poland.

* The Russian/Polish cooperative effort in the ag-air industry is known to be extensive. In general, R&D is centered in the USSR, and production and export are the activities of the Poles. However, Polish R&D is on the increase (Ref. 18). Also, only one manufacturer is counted for Poland, even though production occurs at three plants: Mielec, Okecie, and Swidnik.

The following tabulation summarizes, for the developing countries in Table 2, data similar to those presented above for the developed nations.

Country	Fleet	US Models as Percent of Fleet	Recent Shipments of US Aircraft 1975-1978
Argentina	539	--	84
Brazil	219	32	56
Czechoslovakia	92	--	0
India	50	--	0
Mexico	800	--	7
Poland	50	--	0
Romania	--	--	0
Yugoslavia	46	15	11

Within this group, Argentina, Brazil, and Yugoslavia have all received large shipments of US airplanes recently, indicating good penetration by US manufacturers. However, Brazil's Ipanema comprises almost 70 percent of that country's fleet (Ref. 19), and over 300 of these airplanes have been produced for Brazil, Uruguay, and Paraguay (Ref. 20). Furthermore, Brazil's import tariff policies have made US penetration of the Brazilian market increasingly difficult in recent years (Ref. 17).

Mexico's fleet is quite large, but apparently deceptively so since the use rate of these airplanes is low (150 to 200 hours per year per aircraft, according to Ref. 10). Although the market for ag-airplanes in Mexico is thought to be large (Ref. 21), recent US shipments have been meager. Like Brazil and other countries, Mexico has protected its manufacturers by import duties. But in the long term, the inability of the domestic industry to meet expected demand for airplanes should open that market to US manufacturers. In any case, the Mexican industry is unlikely to compete with the US except for the Mexican domestic market.

For a country of India's size, its ag-air fleet is quite small (Ref. 19). It is not known how many US aircraft, if any, are operating in India, but it has not been an important market for the US, as indicated by the lack of sales in recent years. Although India has an active manufacturing industry, it is not a competitor to the US in the agricultural aircraft market.

The Eastern European Communist nations have relied exclusively on their own aircraft. As shown in the above table, there have been no shipments of US airplanes to Czechoslovakia, Poland, or Romania. However, while the US has not marketed its airplanes to this bloc, neither do the Eastern European nations export their products directly to the West, although Poland has made some initiatives in this direction. An attempt at a cooperative venture with

Rockwell International in the development of the M-18 Dromader is one example. Other examples are exhibition of its aircraft in Western air shows, and exploratory moves to have its Shvetsov ASz-621R 746 kW (1000 HP) radial engine adopted as a replacement for out-of-production US engines (P&W R-1340, Wright R-1300), for which the supply is being depleted.

The above arguments indicate that, of all the countries producing ag-airplanes, only Poland is in a position to compete effectively with the US in the future. The Polish industry produces a wide variety of models, including the large An-2 and M-15 aircraft, which have capacities far in excess of US models. The M-15 is unique both in its large size and in its turbofan-powered biplane design. However, it appears to be uniquely tailored to high-volume aerial fertilizing, and its application elsewhere in the world will depend on its ability to penetrate the fertilizer market which has been traditionally served by ground equipment. Even the Poles do not plan to operate the M-15 because the fields in Poland are much smaller than in the USSR and are 85 percent-owned by small farmers. Some 3000 M-15s have been ordered by the USSR and, as of mid-1977, 100 had been delivered (Ref. 22).

It is conceivable that other countries with established aircraft industries, but not presently producing agricultural models, could enter the picture in the future. The United Kingdom, Japan, and West Germany are examples of qualified entrants to the ag-aircraft market. However, none of these countries is a major user of aircraft in agriculture. (The most recent fleet estimates from Ref. 10 are: UK - 116, Japan - 173, and West Germany - 18). Without a large domestic requirement to serve as a reliable production base, they are unlikely to join this already competitive marketplace.

Another competitive factor, and one which may weigh heavily in the future marketing of ag-airplanes in developing countries, is the export of complete agricultural services utilizing aircraft. At present, CIBA-GEIGY (Switzerland) and ZUA (Poland) are active in this field, primarily using aircraft supplied by affiliated domestic manufacturers (Pilatus in Switzerland and PZL in Poland). The advantage of such a service to a developing country is that the technological and managerial infrastructures normally prerequisite to an ag-air program need not be present to take advantage of the benefits of aerial applications when a fully qualified team of foreign technicians and managers is hired to execute a complete program. Disadvantages are that the service may be expensive, the developing country may not be encouraged to develop its own capability under these conditions, minimal domestic employment is stimulated, and a foreign exchange debit is suffered. Nevertheless, the inducement for developing countries to import such services has led to CIBA-GEIGY programs in Indonesia, Bangladesh, Pakistan, Sudan, Egypt, Saudi Arabia, Morocco, Ghana, Nigeria, Zaire, and the Central African Republic, and ZUA programs in Egypt, Sudan, Libya, Tunisia, Algeria, and several East European countries (Refs. 23 and 24).

A breakdown of fleets by major world regions is provided in Fig. 6, showing that the USSR and the US account for 72 percent of the total world fleet, the Latin American countries (including Mexico) account for an additional 11 percent, Oceania and Canada account for about 7 percent, and the remaining 10 percent is fragmented among the Asian, African, and European groups. However, Fig. 6 indicates only which regions are the primary users of ag-airplanes; it cannot necessarily be inferred that these same regions are the major markets for US-manufactured models.

A detailed accounting of US agricultural aircraft shipments since 1960 appears in Table 4. This tabulation shows how many of each model were shipped, and what portion of these were export shipments since 1970*. A plot of these data is given in Fig. 7; figures for 1978 were projected on the basis of shipments through May 31, 1978. The sharp rise in shipments in the early 1970s was dramatic, but was not sustained. Thus, cumulative shipments have trended upward as depicted in Fig. 8.

Although the average size of the airplanes shipped has increased, the value of shipments has not increased faster than units shipped. Using the average takeoff weights and airplane prices indicated in Table 4, Figs. 9 and 10 show these trends. Average takeoff weight increased markedly in the early part of the period shown in Fig. 9, but has remained relatively constant since then. Exported airplanes have been, on the average, slightly smaller than those purchased by US operators. Comparing Fig. 10 with Fig. 7, it can be seen that the trends in value of shipments and units shipped are almost identical from about 1968 to the present.

An analysis was made of recent exports of US ag-airplanes to determine the nature of the world market. Data were obtained from GAMA for the period January 1, 1975 to May 31, 1978, and shipments were divided into the same world regions indicated in Fig. 1, except that the USSR, China, and the Eastern European nation groups did not apply since no US shipments were made to these groups. The US is obviously not included as a recipient of export shipments. The results of this analysis are presented in Figs. 11 to 15 for various model groupings, and in Fig. 16 for the total of all US models exported.

The one consistent trend in Figs. 11 to 15 is that Tropical Latin America has been the major market for all of the airplane model groupings except the Piper Pawnee; the greatest number of Piper Pawnee exports was to Temperate Latin America. Europe was also an important market for the Pawnee, but less so for the Pawnee Brave. Although the Cessna models were exported to every region, the Tropical Latin American countries were clearly the major purchasers. Among the larger airplanes, the Grumman Ag Cat sold well in

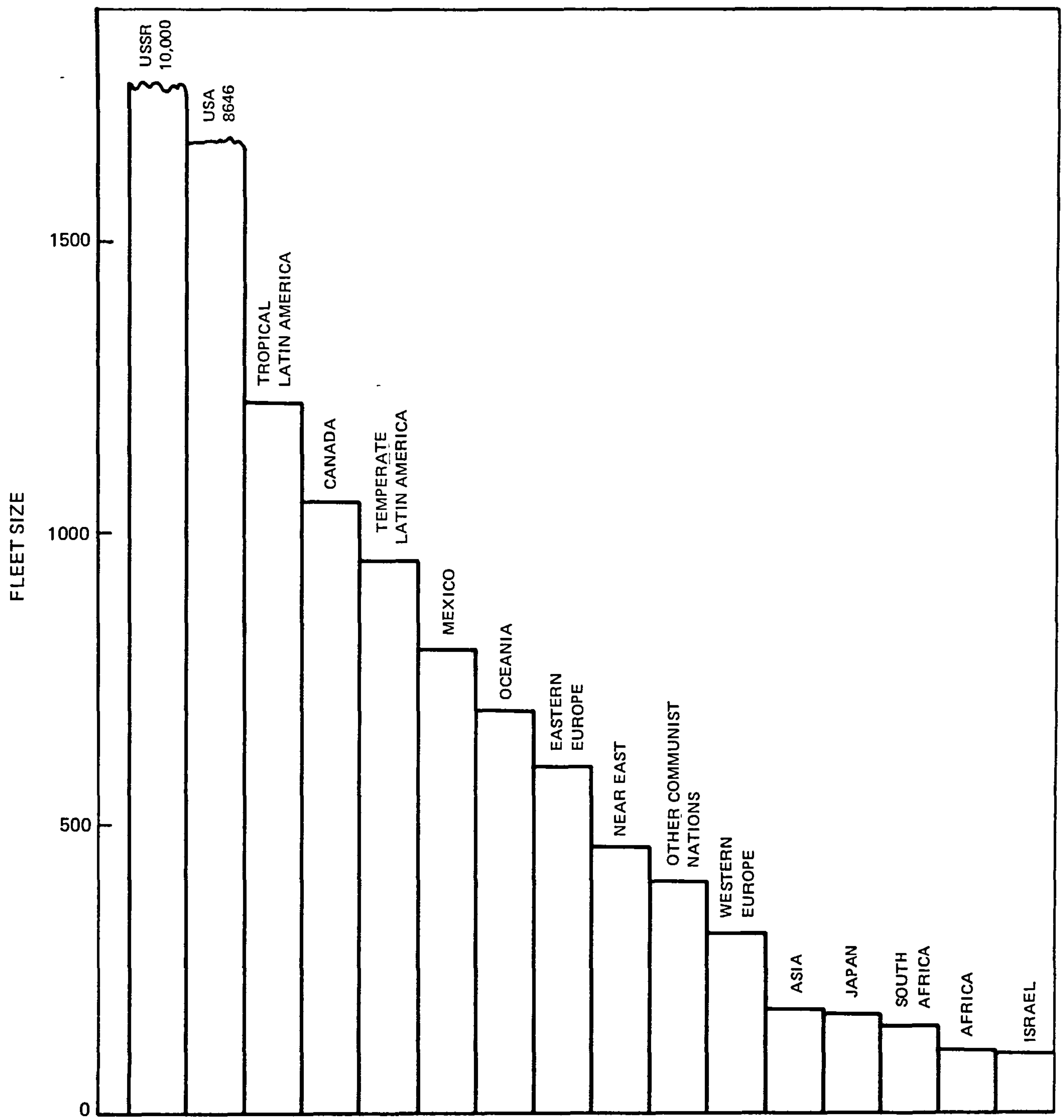
---

*Data from 1970 to the present were gathered by GAMA, whereas earlier data are based on AIA figures, which are not in the same format.

FIG 6

WORLD AGRICULTURAL AIRCRAFT FLEET BY REGION

BASED ON 1976 FLEET TOTAL OF 26,000 AIRCRAFT



79–01–255–2

TABLE 4

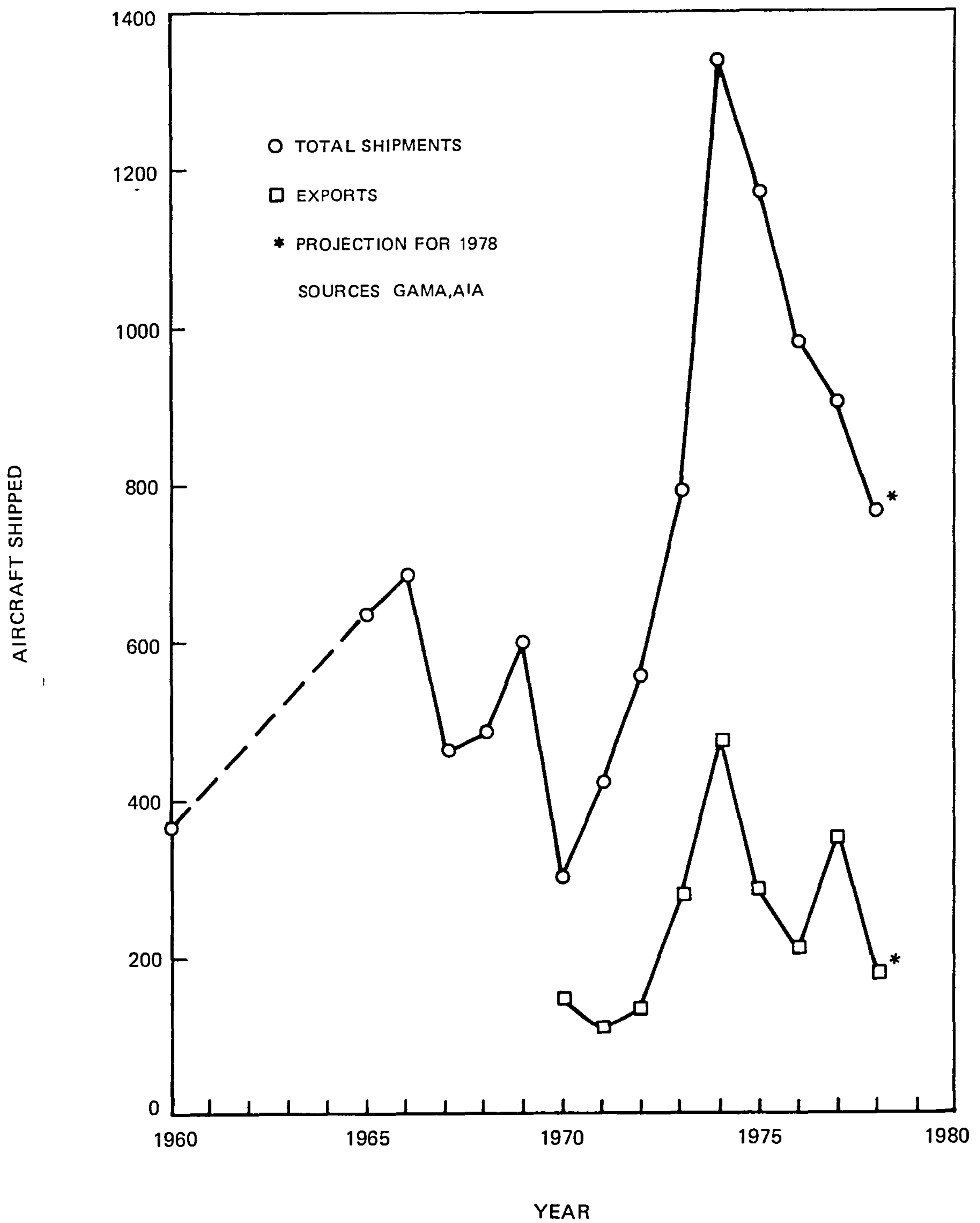
AGRICULTURAL AIRCRAFT SHIPMENTS

SOURCE: GAMA

Manufacturer:		Piper		Cessna			Grumman American	Rockwell International		
	Year	Pawnee 235/260	Pawnee Brave 280/300/375	Ag Carryall/ Pickup	Ag Wagon	Ag Truck	Ag Cat	Thrush (1) Commander 600/800/Turbo	Aero (2) Commander	All US Total
All Shipments	1960	363	-	-	-	-	-	-	-	363
	1965	634	-	-	-	-	-	-	-	634
	1966	432	-	-	193	-	57	-	-	682
	1967	314	-	-	95	-	52	-	-	461
	1968	211	-	-	143	-	-	-	130	484
	1969	206	-	-	148	-	-	45	201	600
	1970	138	-	-	118	-	-	47	-	303
	1971	127	-	-	140	-	103	52	-	422
	1972	63	-	30	182	42	142	99	-	558
	1973	42	62	23	169	157	175	162	-	790
	1974	328	40	24	155	350	185	253	-	1335
	1975	163	180	38	75	388	228	100	-	1172
	1976	114	71	18	51	333	255	138	-	983
	1977	94	164	12	36	269	207	121	-	903
	1978 (3)	35	52	3	7	86	76	61	-	320
Exports	1970	82	-	-	43	-	-	12	9	146
	1971	36	-	-	48	-	-	20	5	109
	1972	35	-	9	50	7	-	30	1	132
	1973	42	28	9	93	22	24	58	-	276
	1974	160	17	9	83	63	43	100	-	475
	1975	49	32	18	38	75	62	10	-	284
	1976	20	28	9	27	75	18	32	-	209
	1977	72	43	9	27	116	41	38	-	351
	1978 (3)	23	20	3	1	21	5		-	73
Avg. Price 1976 $		38,220	55,000	49,400	43,950	49,650	58,800	78,500	65,250	
Avg. Takeoff Weight, kg		1,315	1,769	1,520	1,814	1,905	2,756	3,463	3,300	

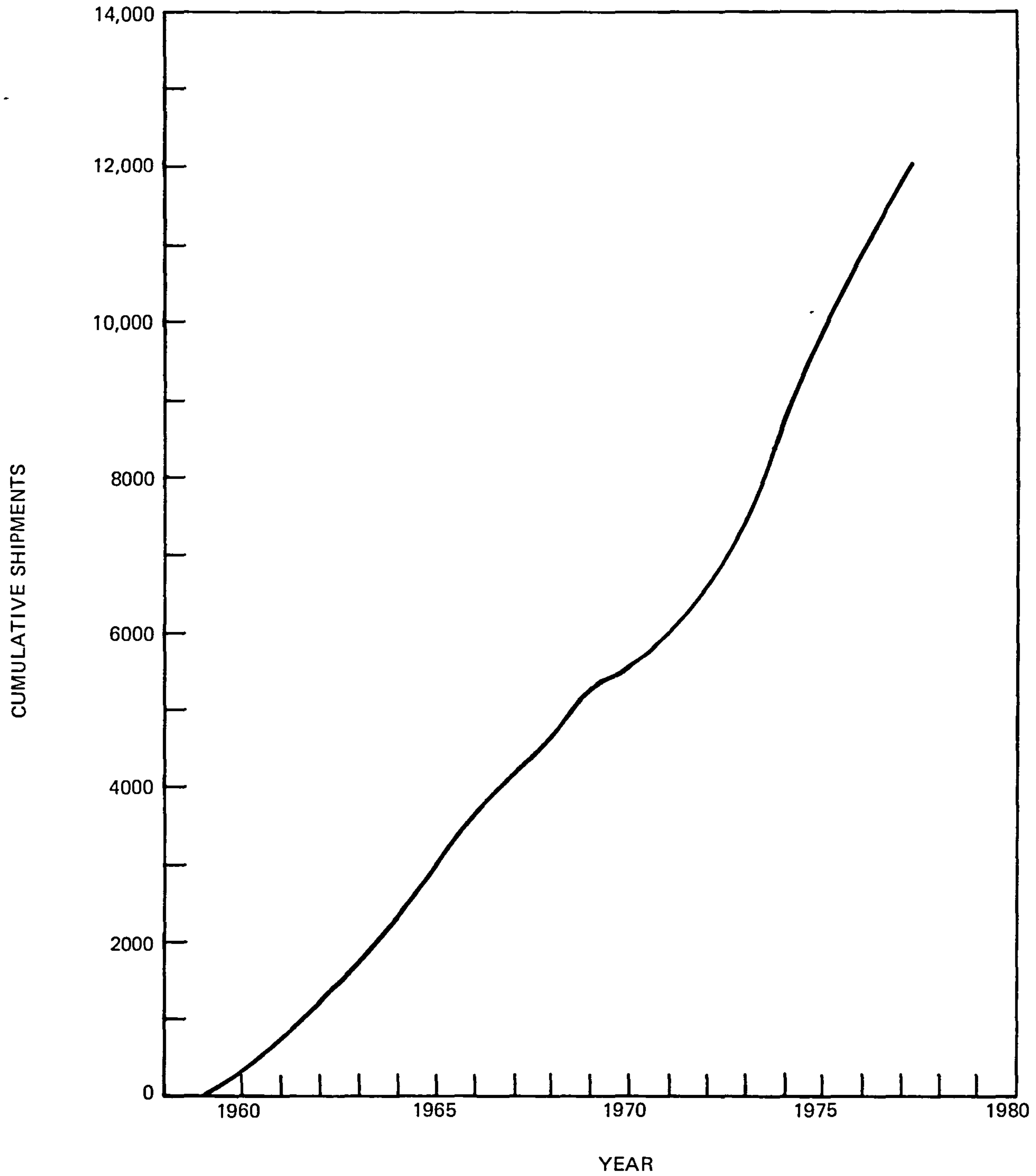
(1) Production by Fred Ayres in 1978 - (2) Includes Lark, Sparrow, Quail, Darter - (3) 1978 Data thru May 31, 1978

SHIPMENTS OF U.S. AGRICULTURAL AIRCRAFT



78–07–17–4

CUMULATIVE SHIPMENTS OF U.S. AGRICULTURAL AIRCRAFT



78–07–17–5

AVERAGE TAKE OFF WEIGHTS OF U.S. AIRPLANES SHIPPED

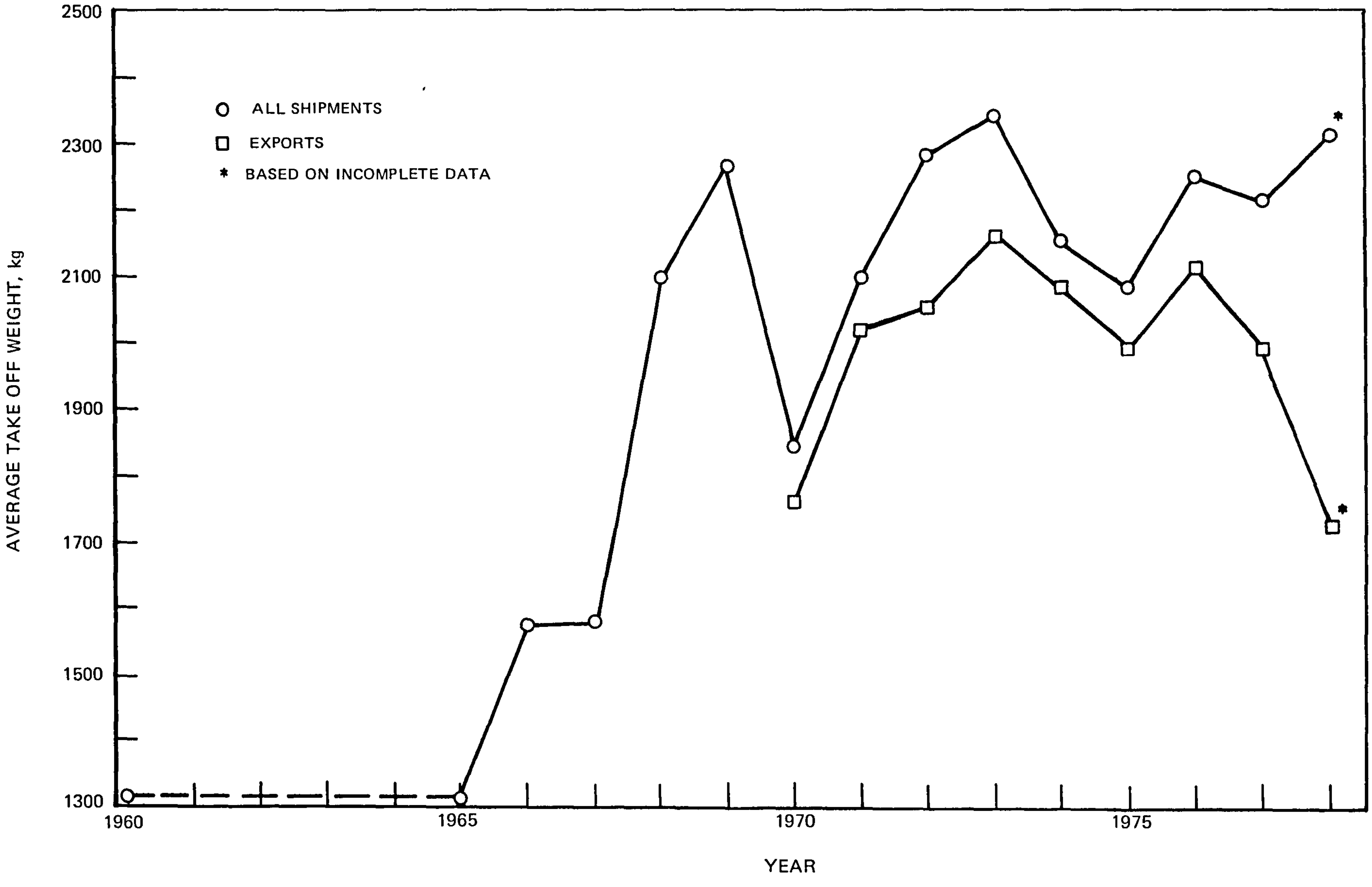


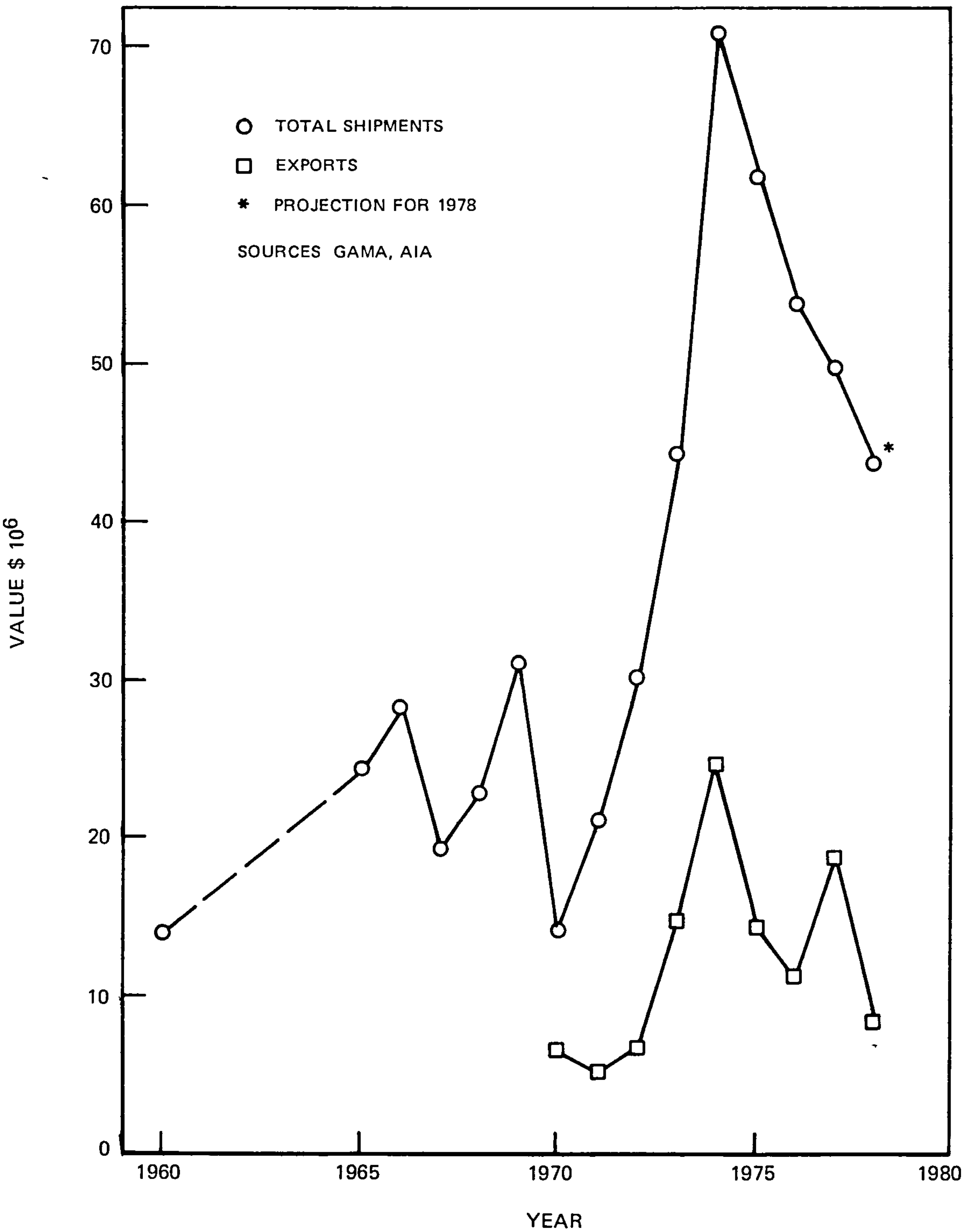
FIG. 9

78-07-17-6

FIG. 10

VALUE OF U.S. AGRICULTURAL AIRCRAFT SHIPMENTS

CONSTANT 1976 DOLLARS



78–07–17–7

U. S. AGRICULTURAL AIRCRAFT EXPORT SHIPMENTS BY REGION

MANUFACTURER CESSNA

MODELS AG WAGON, AG CARRYALL, AG TRUCK

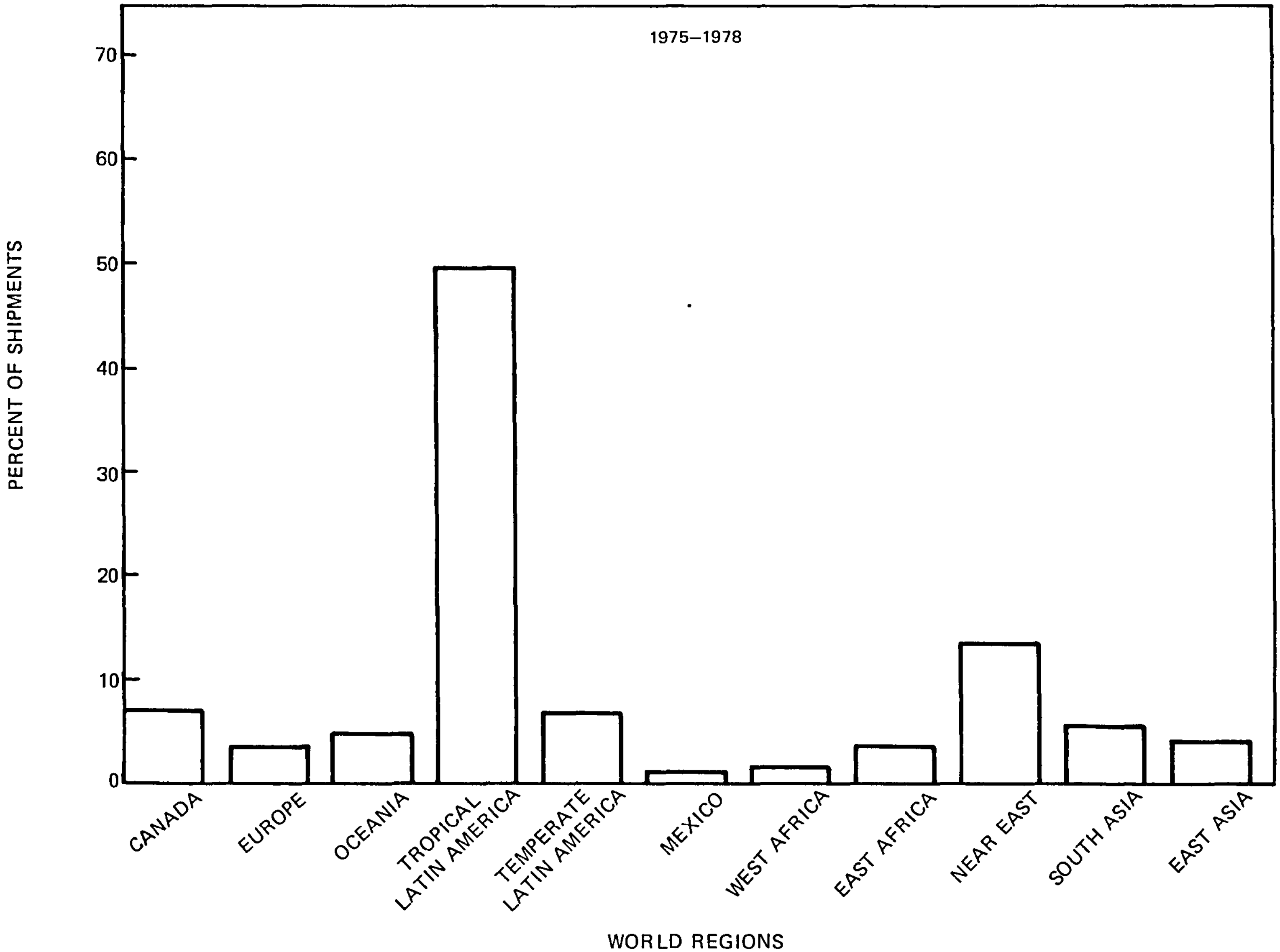


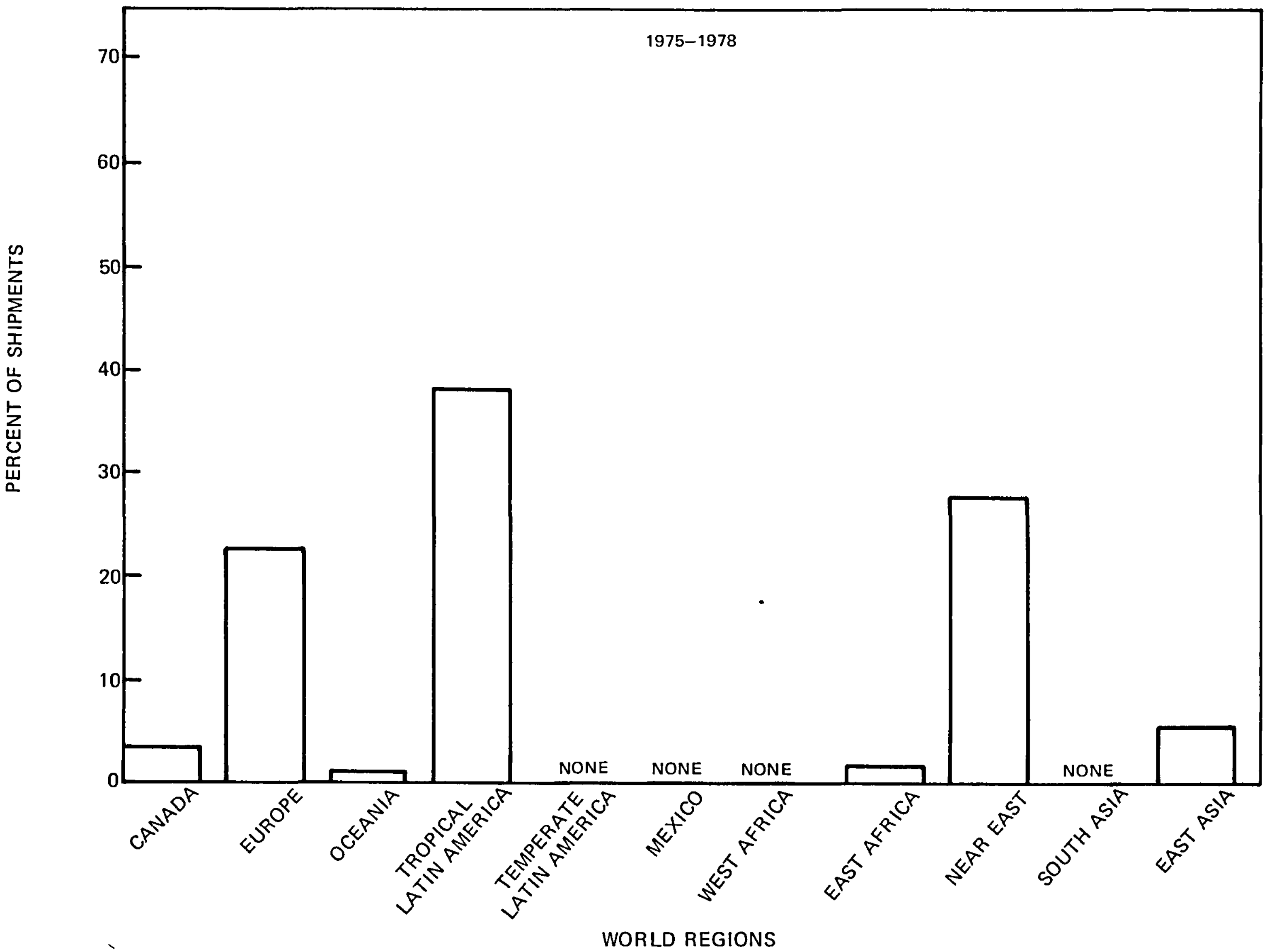
FIG. 11

78–07–17–8

U. S. AGRICULTURAL AIRCRAFT EXPORT SHIPMENTS BY WORLD REGIONS

MANUFACTURER GRUMMAN AMERICAN

MODELS AG CATS A, B, C



78–07–17–9

FIG 12

U. S. AGRICULTURAL AIRCRAFT EXPORT SHIPMENTS BY REGION

MANUFACTURER PIPER

MODELS PAWNEE 235,260

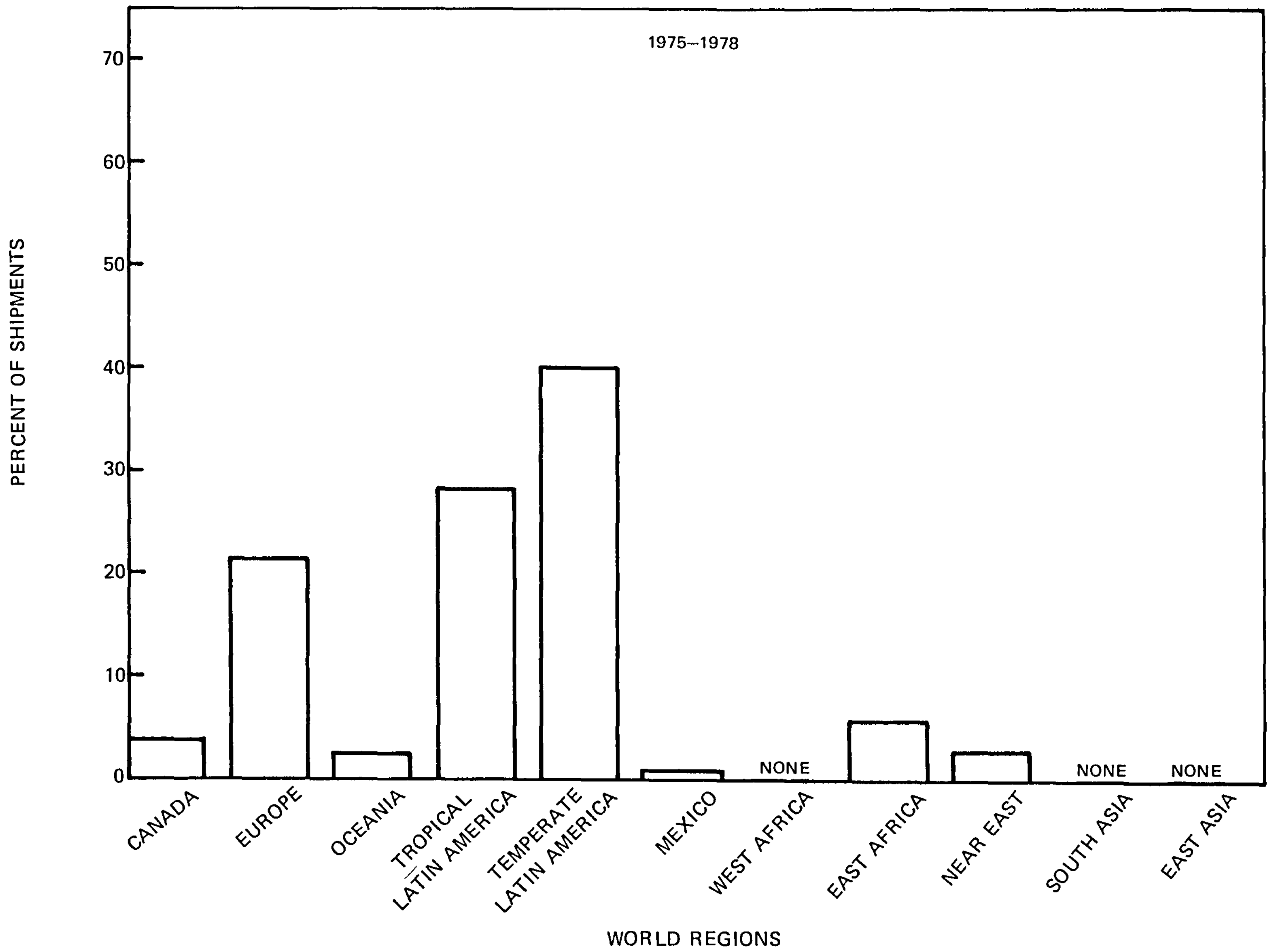


FIG 13

78–07–17–10

U.S. AGRICULTURAL AIRCRAFT EXPORT SHIPMENTS BY REGION

MANUFACTURER PIPER

MODELS PAWNEE BRAVE 285,300,375,380

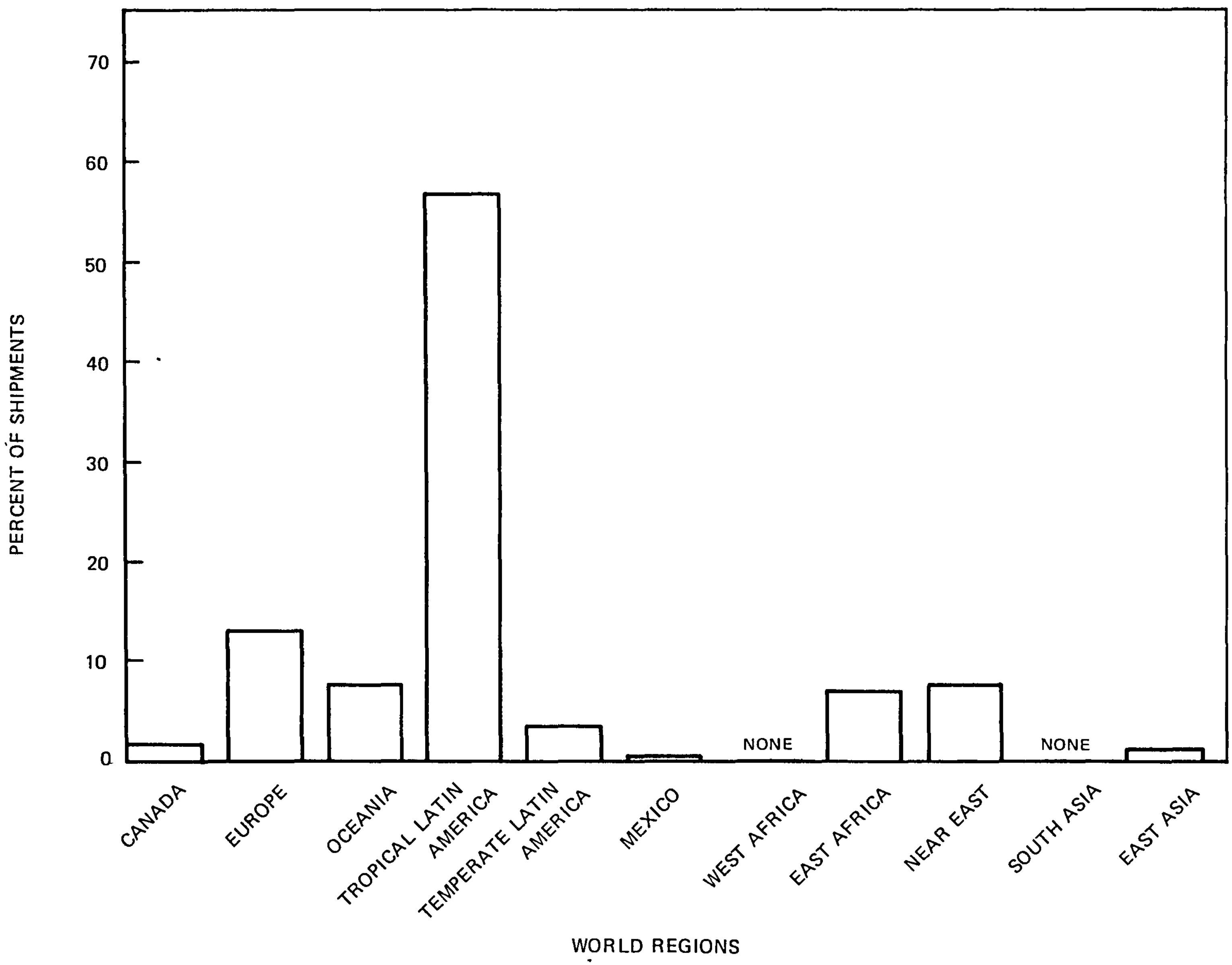


FIG 14

U.S. AGRICULTURAL AIRCRAFT EXPORT SHIPMENTS BY REGION

MANUFACTURER ROCKWELL INTERNATIONAL/AYRES

MODELS THRUSH COMMANDER 600,800, TURBO

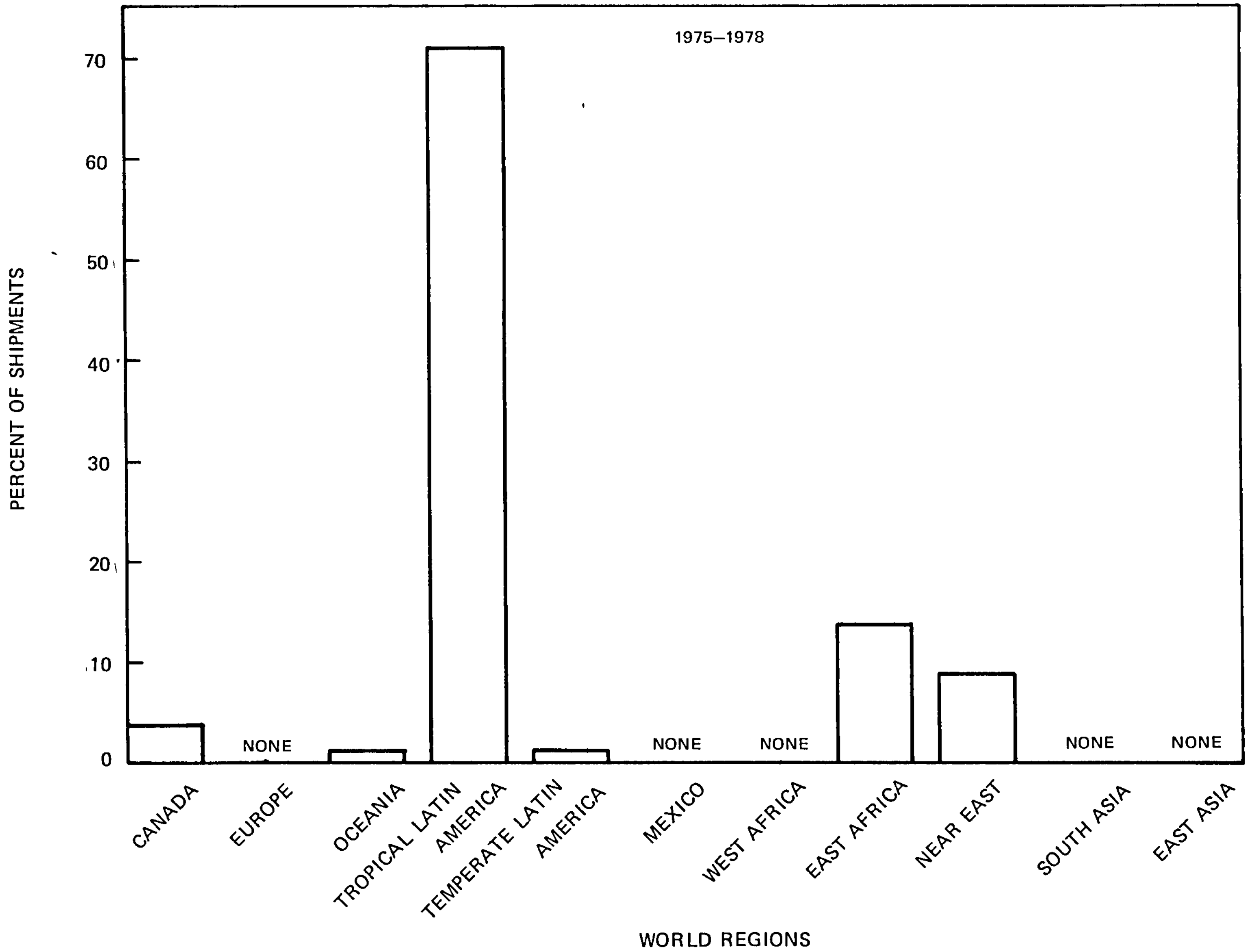


FIG 15

78–07–17–12

U.S. AGRICULTURAL AIRCRAFT EXPORT SHIPMENTS BY REGION

ALL U S MODELS

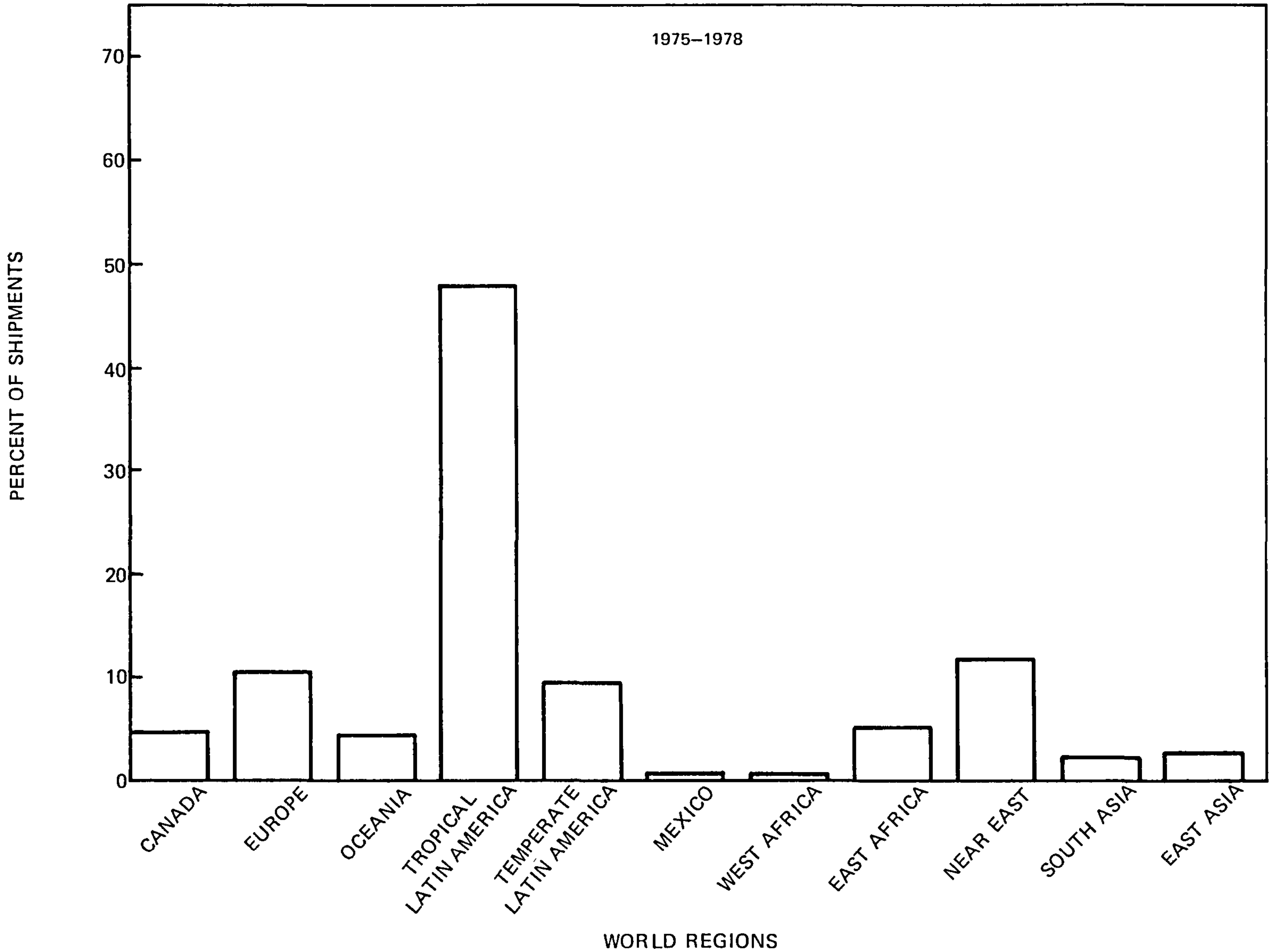


FIG 16

78–07–17–13

Europe and the Near East as well as Tropical Latin America, but the secondary markets for the Thrush Commander series, East Africa and the Near East, were much smaller. The fact that only certain manufacturers have access to particular markets because of government licensing policies (usually contingent on some degree of local manufacture) causes some distortion of these data. For example, Piper and Cessna models are assembled in Colombia for distribution to the Andean Pact nations -- Bolivia, Chile, Colombia, Ecuador, and Peru. Thus, operators in these countries can purchase Piper and Cessna models without the large import duties imposed on other aircraft such as the Ag Cat and Thrush. Since the latter are the largest US-made aircraft, exports to this region would naturally show some bias toward smaller aircraft. However, because the market structure adopted here incorporates both Central and South American nations into the Tropical Latin America category, this bias is not evident in the data. Similar situations also exist in other parts of the world because of the desire of developing countries to promote local manufacture of airplanes (Ref. 17). Also, some nations act as distribution points for deliveries to their region (Switzerland for European countries, US for Canada) thereby tending to distort export statistics.

The dominance of the Tropical Latin American nations as a market for US agricultural airplanes in recent years is shown clearly in Fig. 16. Almost half of all shipments went to each of the next three biggest markets -- Europe, Temperate Latin America, and the Near East. Canada, Oceania, and East Africa each accounted for about 5 percent, and the remaining 6 percent was spread among the other four regions. It is also important to note that developed countries are confined to the first three bars (Canada, Western Europe, and Oceania) in Fig. 16 and that they comprise less than 20 percent of the shipments outside the US. Thus, the developing nations have been the primary base of the US export market for agricultural aircraft, and Latin America has been the most important region for such exports.

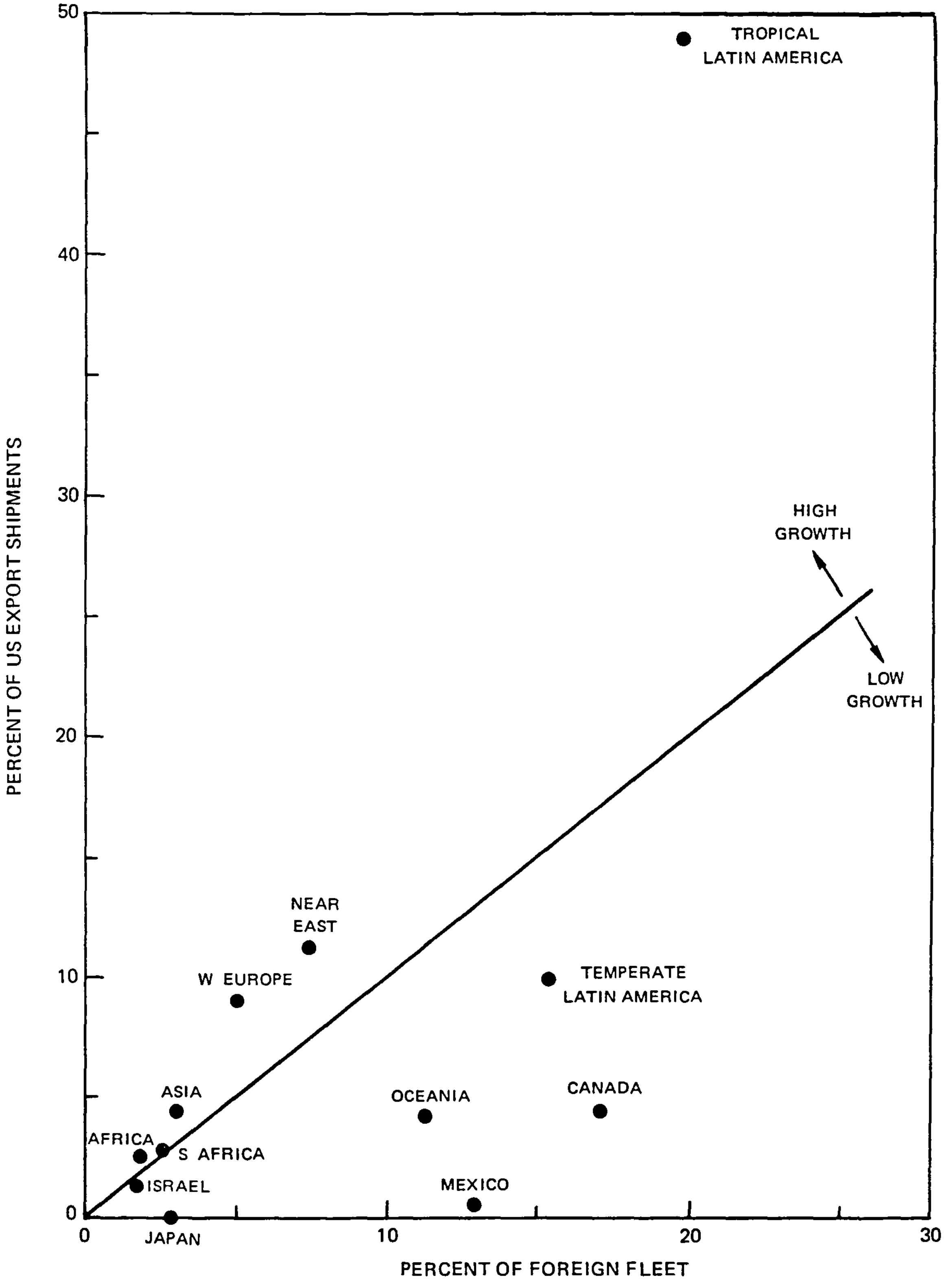
When the shipment data of Fig. 16 are compared with existing foreign fleet data from Fig. 6, an idea of recent ag-air growth trends can be gained. The plot in Fig. 17 shows the percent of the foreign ag-air fleet (excluding USSR and other communist nations) in each region compared to the percent of recent US shipments to each region. If the entire foreign fleet and all recent deliveries consisted exclusively of US aircraft, this chart would provide a definitive statement about the relative growth of current ag-air markets. However, even though US aircraft dominate in the non-communist fleet, there are enough regional exceptions to cloud the picture. Nonetheless, there can be no question that the Tropical Latin American region is presently the high-growth market for ag-aircraft.

Future Market Growth

The previous section has documented historical growth patterns in the aerial applications industry, including recent trends in each world region.

COMPARISON OF US EXPORTS AND FOREIGN FLEETS

EXCLUDES USSR, EASTERN EUROPE AND OTHER COMMUNIST NATIONS



79–01–255–1

In this section, projections are developed for the same regions to the year 2000 in order to identify the types of aircraft which will be required in this future period and their expected distribution by world region. Because of the importance of the US ag-aircraft industry and the credibility of its data, a detailed analysis has been made of the US market. The analysis for other world regions is then developed by a parallel approach, using data characteristic of US operations where necessary, but adapting these data to apply in the foreign environments.

General Approach to Market Analysis

As a first step in projecting the future world requirements for ag-airplanes (number and type), a comparison was made of calculated and actual aircraft use rates, in which the calculated values are based on US usage patterns described in Ref. 10. Aerial treatment estimates were made in each of the crop categories enumerated in Table 5. The basic categories were adopted to coincide with US usage, and additional crop varieties were included under appropriate primary crops in order to cover crops important in other parts of the world. Using US production figures for 1976 from Ref. 3 and the aerial treatment breakdown by crop in Ref. 10, scaling laws for aerial treatment were developed, the coefficients of which are given in Table 5. They are expressed as the treated area (ha) per unit production (10^3kg), and indicate the relative intensity of aerial application in the US. Knowing crop production rates for any world sector, these coefficients can be used to estimate aerial treatment area. However, it is essential to recognize that the estimates so calculated will describe what the treatment area would be if US usage patterns were prevalent thoughout the world. Clearly, ag-aircraft are used more liberally in the US than elsewhere, although uses in many other developed countries should closely approximate US practice. Therefore, estimates of treated area calculated by these coefficients should be more accurate for developed countries than for developing countries.

A comparison of calculated and actual treated areas for 1968 and 1976 is provided in Fig. 18 for various developed and less-developed regions. Not all countries in the regions shown are included since data are available only for selected nations in each region. Also, data for both 1968 and 1976 are available for only a small number of countries in each region. Where data for both years are indicated in Fig. 18 (by triangular and circular symbols), the countries representing each region are those for which data for both years were available. Although this presentation is based on only a limited amount of data, it is effective in indicating some important trends.

The diagonal line represents equality between actual and calculated values. Because the calculated areas are based on US practice in 1976, the 1976 point for North America falls on the line. Since ag-aircraft usage is greater in the US than most other countries, the calculated values ought to be higher than actual values, and most points should fall below the line. Points closest to the line most closely approximate US practice. In general,

TABLE 5

BASIS FOR AERIAL TREATMENT AREA ESTIMATES

Treatment Category	Other Crops Covered	1976 U.S. Production (10^6kg)	% of Aerial Treatment Area	Coefficient
Wheat		58,444	8.1	0.10
Paddy Rice		5,308	17.4	2.39
Corn		157,893	6.3	0.03
Sorghum		18,382	6.2	0.25
Other Grains	Rye, Oats Millet, Barley	17,036	5.5	0.24
Cotton	Flax, Fibre Crops, Rubber, Jute	5,959	26.6	3.25
Tubers	Roots	16,658	2.6	0.11
Vegetables	Melons	23,311	6.5	0.20
Dry Beans	Broad Beans, Dry Beans, Coffee, Cocoa	782	2.2	2.00
Soybeans	Palm Kernels, Olives, Cottonseed	38,159	7.0	0.13
Nuts	Groundnuts, Treenuts	2,138	1.8	0.60
Sugar Cane	Sugar Cane, Sugar Beets	52,814	0.9	0.01
Citrus	All Citrus Fruits	13,410	2.2	0.12
Fruit	All Non-Citrus Fruits	10,688	0.7	0.05
Tobacco	Tea	961	0.4	0.33
Forest	Log Output/ Forest Area	11.1 m^3/ha	0.5	303 10^3 ha/m^3/head
Rangeland	Cattle and Sheep	141 x 10^6 head	4.1	21 10^3 ha/10^6/head
Area Insect Control	Arable, Permanent Crop and Pasture Lands	424 x 10^6 ha	1.2	2.1 10^3 ha/10^6 ha

COMPARISON OF ACTUAL AND PREDICTED AERIAL TREATMENT AREAS

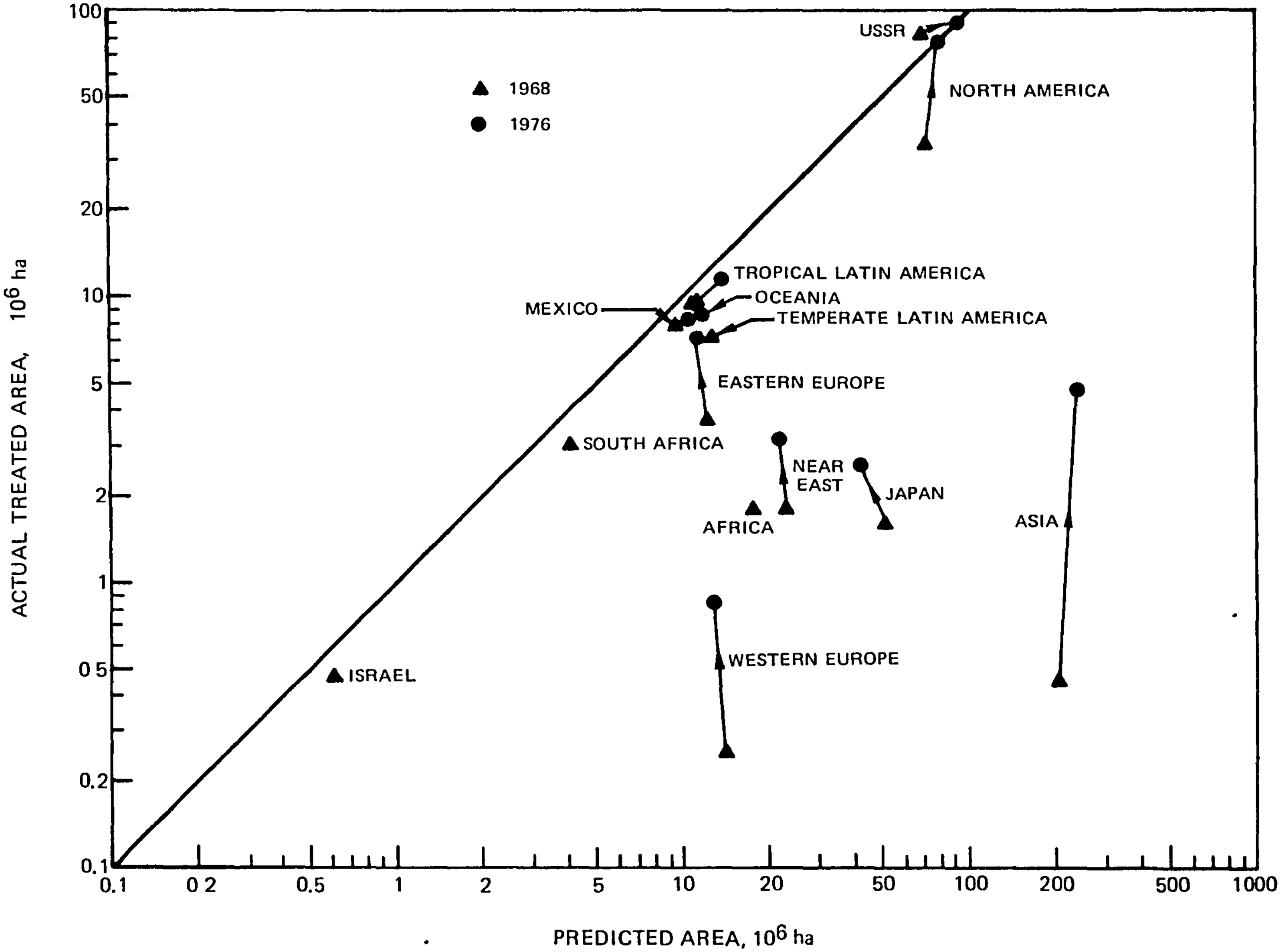


FIG. 18

78–09–31–1

it can be seen that the developed countries are close to the line (exceptions are Japan and Western Europe), and developing country groups are well below it. Also, substantial progress, in terms of increased use of ag-aircraft, is indicated by the upward shift between 1968 and 1976. Since actual crop production figures were used in making the calculations, this shift can either be explained by a more extensive variety of uses being adopted in the past decade or by greater productivity (ha/yr/aircraft) of aircraft. Since an analysis of productivity data reveals only a 3.5 percent increase for the world fleet during that period, the latter solution cannot explain the trend indicated in Fig. 18.

The discrepancies between actual and calculated areas were hypothesized to be caused, at least in part, by the effect of field size because the observation was made that in regions where average field sizes were known to be close to that of the US, the disparities between calculated and actual treatment areas were less than for regions with smaller fields. This hypothesis is confirmed in principle in Fig. 19, which relates the ratio of calculated-to-actual aerial treatment area to the average size of agricultural holdings in each world region in 1960.* The correlation shows that field size is an important factor in explaining the use of airplanes in agriculture. (Note that North America shows a ratio of 2.0 rather than 1.0 because data are for 1960, whereas the calculation is based on 1976 usage patterns in the US.) Although the anticipated trend is evident in Fig. 19, the spread in the data is considerable. Even when a best-fit curve is drawn to represent the most reliable data points (regions rather than individual countries), it would not be a valid "correction factor" to rationalize the discrepancies in calculated and actual treatment areas.

A more intensive analysis of agricultural holdings was conducted to determine whether a more accurate criterion than average holding could be identified. Using data from the 1960 world agricultural census (Ref. 25), it was found that a breakdown of holdings into various sizes was available for numerous countries. The data show what percentages of holdings and of total agricultural area are represented in each of eleven groupings ranging from one hectare up to 1000 hectares. After some experimentation, it was found that an excellent criterion is the percentage of cropland** area in holdings larger than 100 hectares. Although the number of countries for which these data were available is less than the number for which average holding size is known, Fig. 20 shows that a surprisingly good correlation occurs when

*Note that agricultural holdings are entire farms, which are usually much larger entities than individual fields. While considerable data are available for agricultural holdings from Ref. 25, field size data are not obtainable.

**Cropland is more specific than agricultural area in that it excludes permanent meadows and pastures, and forest land.

EFFECT OF AVERAGE AGRICULTURAL HOLDING SIZE ON TREATMENT AREA ESTIMATE

SOURCES REFS 3 AND 25

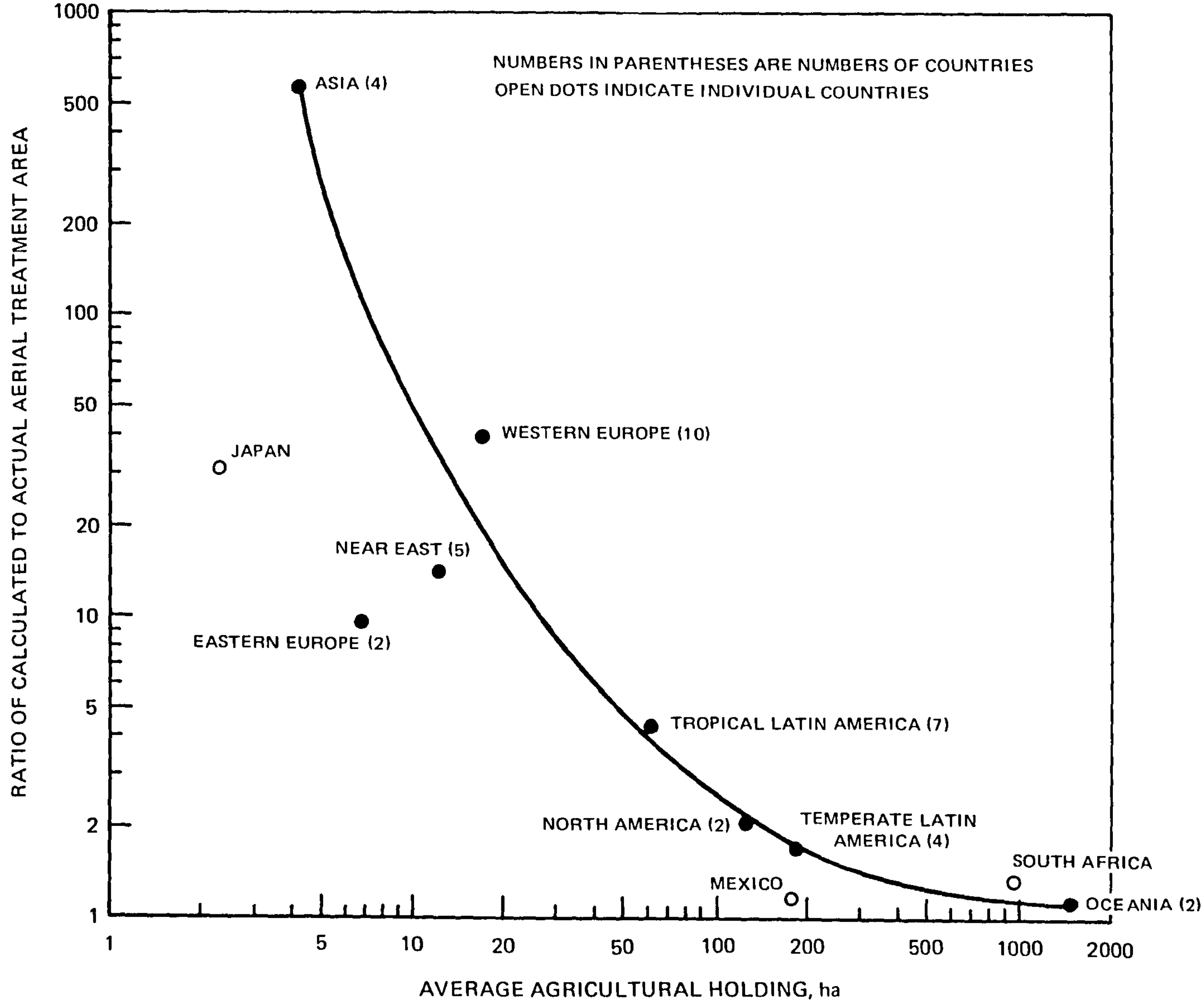


FIG 19

78–10–54–2

FARM SIZE CORRECTION TO TREATED AREA

SOURCES REF 25

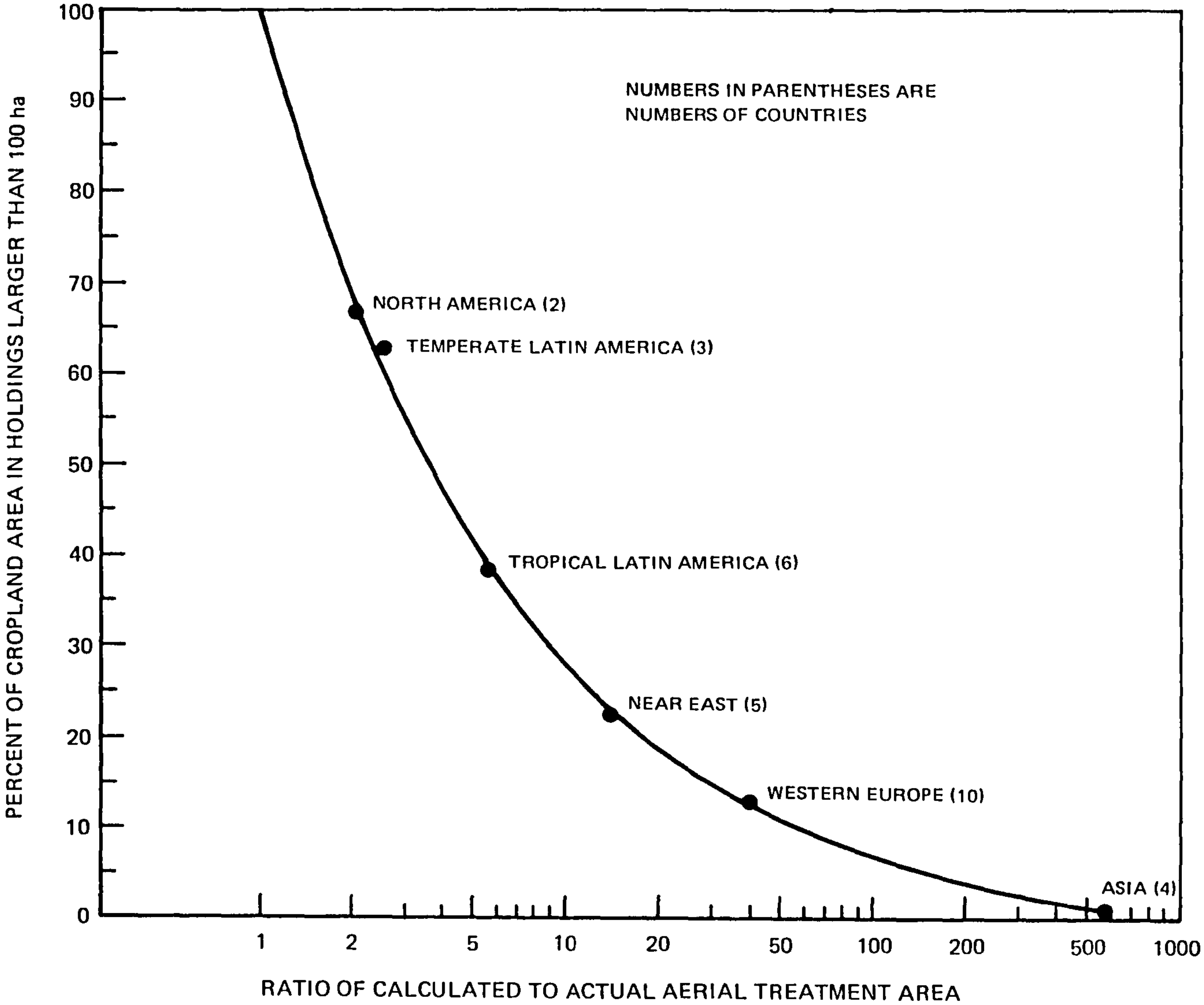


FIG 20

78–10–54–3

this criterion is used to explain the difference between calculated and average treatment areas.

The farm data used to construct Figs. 19 and 20 are subject to change, either because of consolidation of existing farms to form larger units, as has been occurring in the US, or because of land reform policies which are designed to break up large holdings and increase the number of landholders, as has been occurring in Tropical Latin America. Using time series data illustrated in Fig. 21, growth rates were established for the percent of cropland holdings greater than 100 ha in most of the world regions. In other cases, it was necessary to estimate trends based on recent information concerning land tenure programs (Ref. 26). A complete summary appears in Table 6 for the field size criterion in each region based on the 1960 census, projected growth rates, and the expected values in 2000.

Projected US Market

The projection of the farm holding criterion for the US in Table 6 was founded on a voluminous base of data. Historical information on average farm holding size is available from Ref. 27, dating from colonial times up to 1970, and Ref. 28 provides a continuation of trends up to the present. These data are shown in Fig. 22, along with similar data on the percent of land in farms larger than 100 ha. In recent years, the consolidation of US farms into larger units has continued at a reduced rate relative to the post-World War II period. Since the percent of land in large farms can only approach 100 percent in future years, but will not reach it, it is clear that the curve must behave as shown. With this projection of the field-size criterion, Fig. 23 shows what the ratio of calculated to actual area will be in 2000 compared to recent history. The fact that this ratio is predicted to be less than 1.0 simply means that ag-air uses will continue to become more widespread with respect to crops and types of applications compared to 1976. Improved technology and increased acceptance of aerial applications by farmers are the driving factors which will approximately double ag-air use by 2000, irrespective of crop production volume.

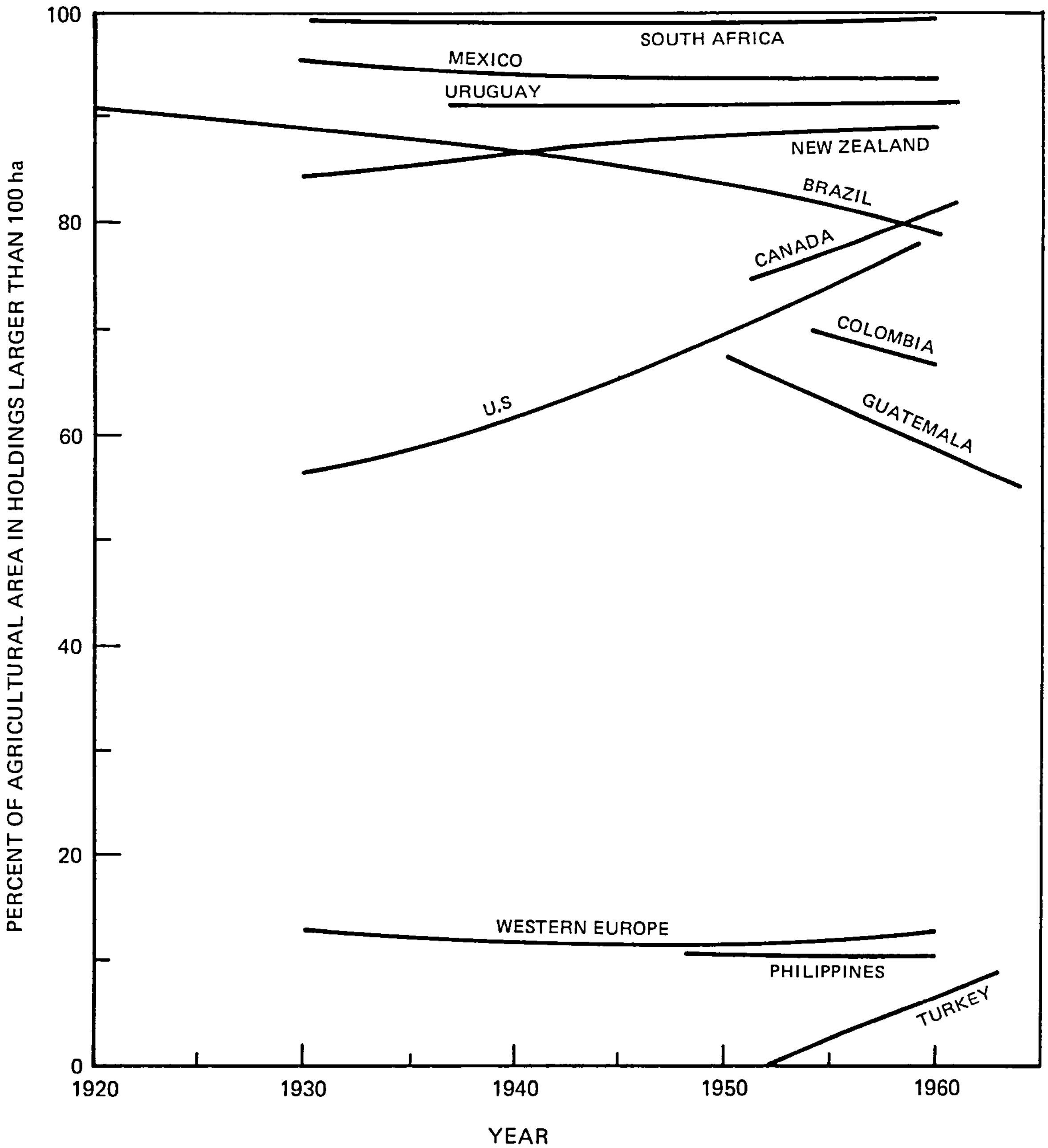
Treated Area

A summary of the procedure for projecting US treated area is given in Table 7. Each of the 18 crop categories is treated separately, based on its production volume. Average production figures for the 1974-76 period were obtained from Ref. 3, and the growth rates shown in the second column are based on continuation of trends established over the 15-year period from 1961 to 1976. These growth rates determine production volumes for each crop in 2000. Estimates of treated area were then made by applying the coefficients in Table 5 to each crop category and dividing by the ratio of calculated to actual treated area from Fig. 23 (1.0 in 1976 and 0.53 in 2000). The history and projection of US treated area are shown, pictorially, in Fig. 24, the growth rate over the 1975 to 2000 period being 5.2 percent/yr. To convert

FIG. 21

TRENDS IN AGRICULTURAL HOLDINGS

SOURCE REF 25



78–10–54–1

TABLE 6

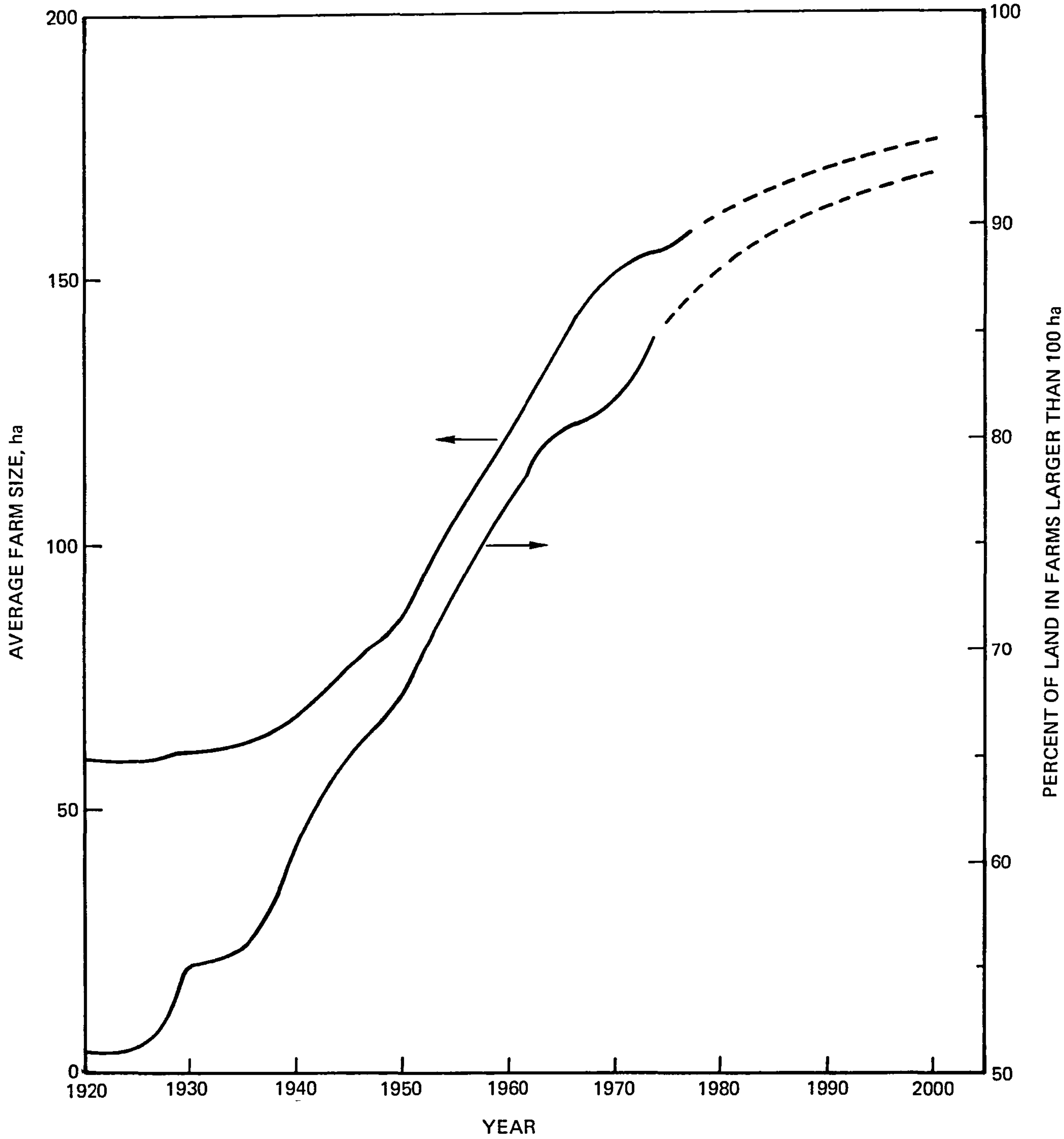
FIELD SIZE CRITERION

Region	1960 % of Cropland in Holdings > 100 ha	1960 Calc. Area / Actual Area	Gr. Rate in Agr. Holdings %/Yr	2000 % of Cropland in Holdings > 100 ha	2000 Calc. Area / Actual Area
North America	68.9	2.0	1.20	100.0	0.53
Oceania	93.6	1.13	0.03	100.0	0.91
Western Europe	13.2	36.0	0.92	19.0	19.0
South Africa	96.4	1.08	0.02	97.0	1.06
Japan	0	31.0	0	0	31.0
Israel*	86.0	1.31	0	86.0	1.31
Trop. Lat. Amer.	41.9	5.0	-0.50	34.0	7.0
Temp. Lat. Amer.	62.6	2.4	0.05	64.0	2.3
Mexico	94.0	1.18	0	94.0	1.18
Africa	19.2	19.0	0	19.2	19.0
Near East	22.4	14.0	0.60	28.0	10.0
Asia	1.73	360	2.80	5.0	140
Eastern Europe	37.0	6.3	1.90	79.0	1.5
USSR*	108.0	0.89	0	100.0	0.89
Other Comm.*	-	-	0	-	-

* Estimate

FIG. 22

FARM HOLDING TRENDS IN THE US



79–01–255–9

US PROJECTION BASED ON AGRICULTURAL HOLDINGS

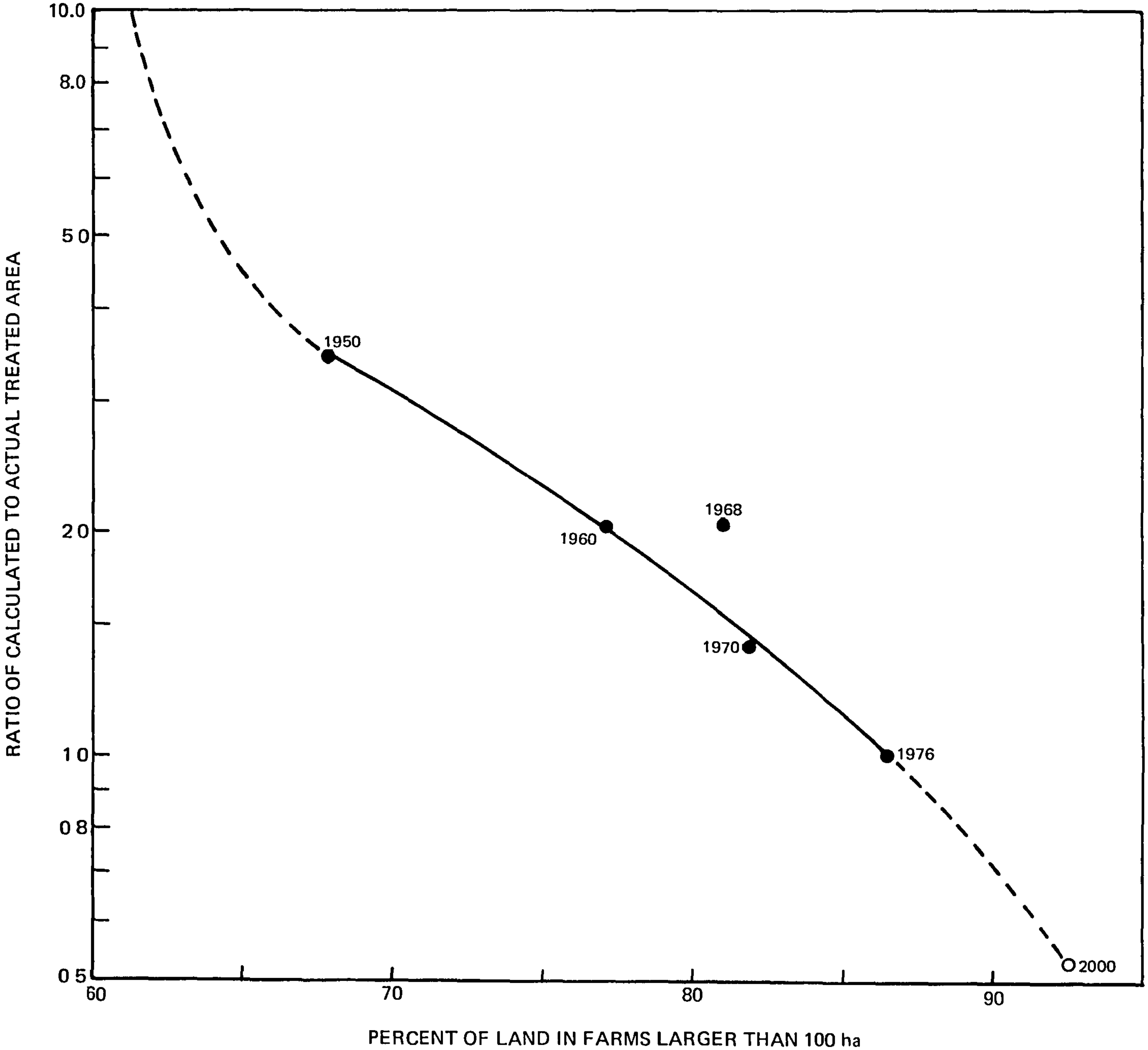


FIG. 23

79-01-255-11

TABLE 7

PROJECTION OF US AG-AIR ACTIVITY

Crop Category	Avg. 1974-76 Production 10^6 kg	Projected Growth Rate %/Yr	Production in 2000 10^6 kg	Estimated Treated Area 10^3 ha 1975	2000
Wheat	55,144	3.5	130,319	5,514	24,589
Rice	5,404	4.8	17,448	12,894	78,549
Corn	141,202	3.4	325,727	4,095	17,823
Sorghum	17,891	2.1	30,080	4,401	13,962
Roots	15,981	1.7	24,357	1,774	5,101
Dry Beans	832	0.4	919	1,664	3,469
Soybeans	40,084	4.0	106,857	5,371	27,017
Other Grains	16,759	3.2	36,833	3,972	16,471
Nuts	2,133	5.4	7,943	1,271	8,933
Sugar	49,405	1.9	79,091	593	1,791
Cotton	5,706	-1.0	4,438	18,545	27,214
Vegetables	24,098	1.9	38,578	4,844	14,630
Citrus	12,938	5.7	51,730	1,540	11,615
Other Fruit	10,992	0.4	12,146	528	1,100
Tobacco	951	-0.1	928	317	583
Timber	1.11*	0.9	1.39*	336	792
Rangeland	144*	0.7	171*	3,024	6,793
Area Insects	424*	-0.2	403*	886	1,590
TOTAL				71,568	262,021

*In units indicated in Table 5

HISTORY AND PROJECTION OF US TREATED AREA

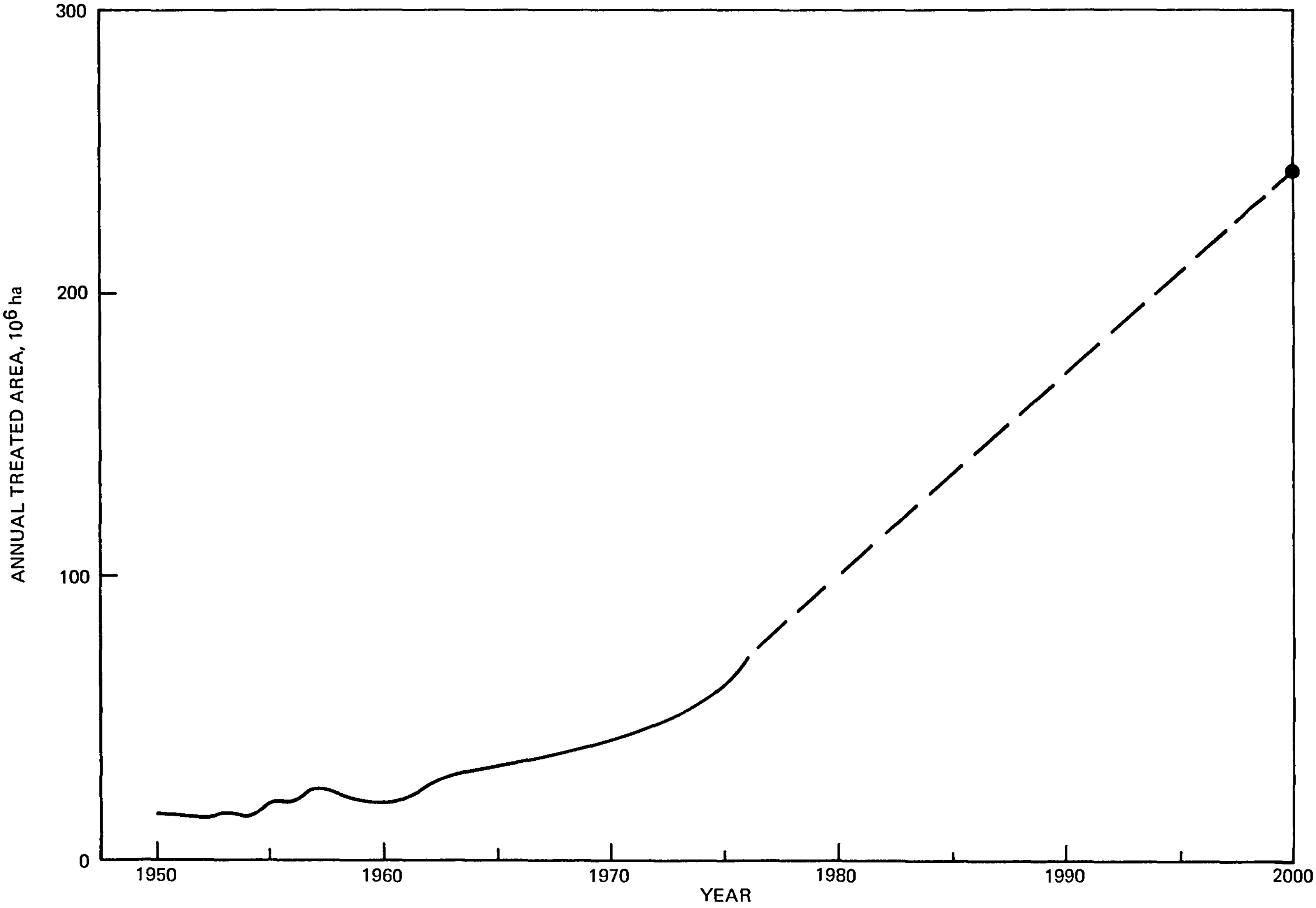


FIG 24

79–01–255–18

HISTORY AND PROJECTION OF US TREATED AREA

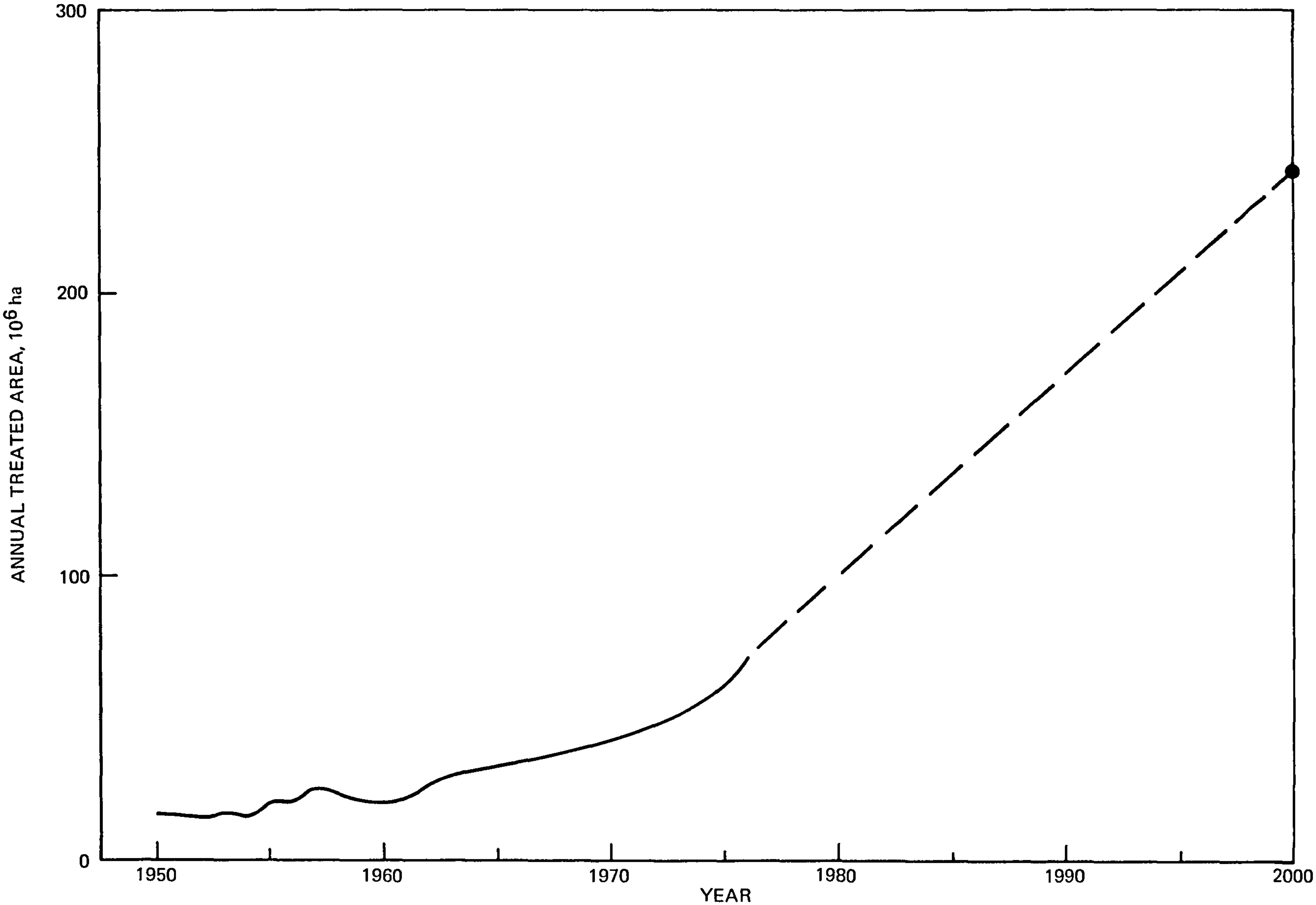


FIG 24

79-01-255-18

this projection of ag-air activity into a requirement for aircraft requires consideration of three operational factors: sizes of aircraft, their productivities, and attrition of the fleet. What follows is a discussion of nominal projections for these factors based on extrapolations of present trends. In a later section, a second projection is made to account for potential structural changes in the ag-air industry, consisting primarily of a more pronounced shift to high-volume applications than that reflected in the nominal forecast.

Productivity

Historical data from Ref. 9 are depicted in Fig. 25, showing that both the utilization and the productivity* of the US ag-air fleet have risen steadily over the 26-year period since 1950. The slightly different trends of hours flown per aircraft and area treated per aircraft are a reflection of the changing structure of the industry and the introduction of specialized aircraft during the 1960s. For projection purposes, it is convenient to use average area treated per aircraft as the basic measure of productivity; the source of such data is the ratio of area treated to fleet size. Thus, Fig. 26 shows the effect of a continuation of the recent trend of 3 percent/yr growth in average productivity. It is not unreasonable to expect significant future productivity gains as the ag-air industry matures further in the next two decades. Improvements in the logistics of operations will be a major factor as demand for ag-air service increases, both in the types of applications and the wider variety of crops. Attrition of older models and deliveries of new ones will improve both the operational and maintenance characteristics of the fleet, thereby permitting each aircraft to spend more time in productive use. Furthermore, since Fig. 25 shows that ag-aircraft are presently utilized an average of only 300 hrs per year, there is considerable room for further progress. There is, undoubtedly, an upper limit to the practical utilization of aircraft in agriculture, particularly when relatively quiescent atmospheric conditions are necessary to prevent excessive drift. However, even the most conservative limit is expected to be more than three hours per day, which offers the possibility of tripling the present utilization.

Fleet Composition

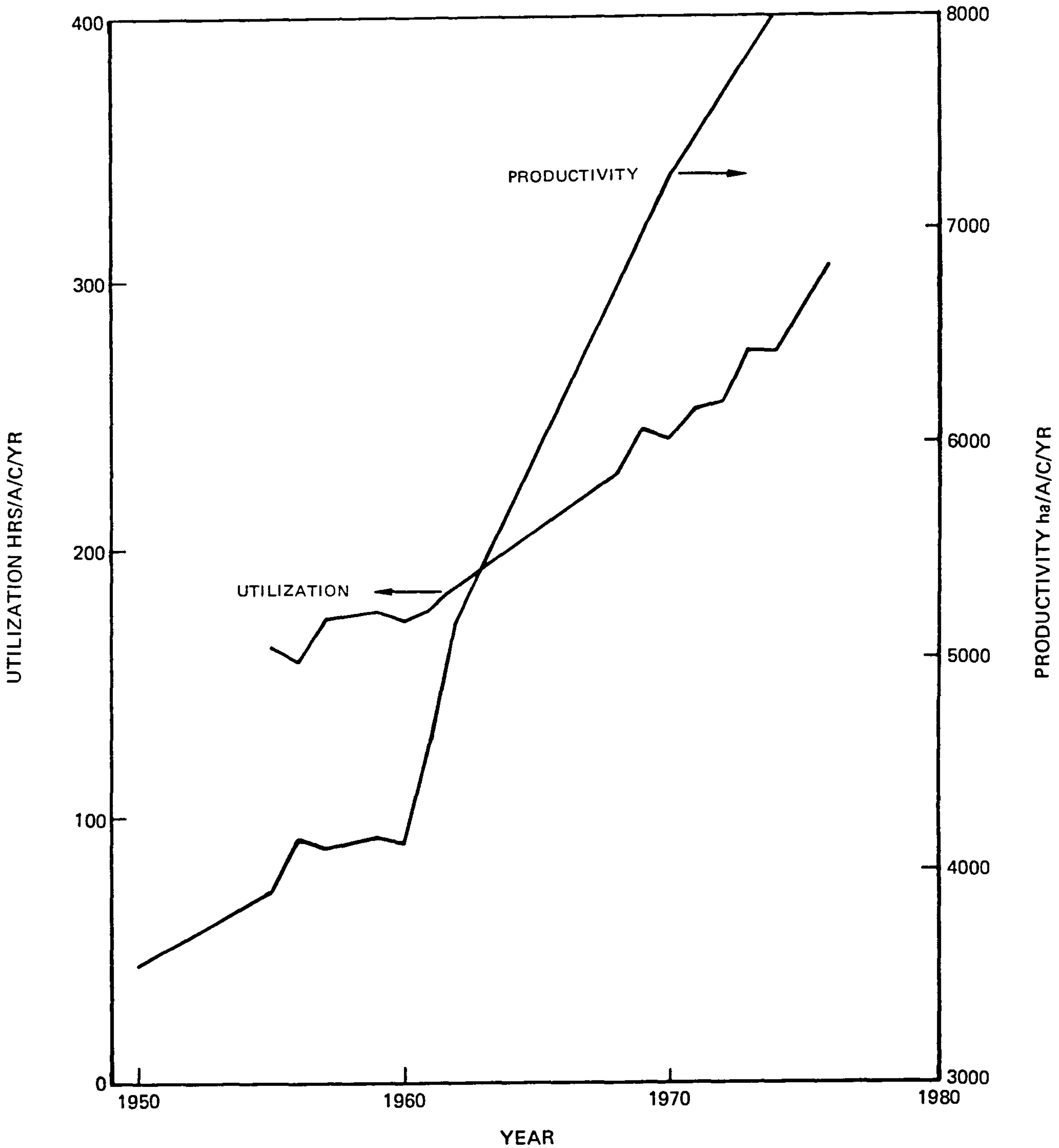
The size of the US ag-air fleet has grown rapidly (although erratically) in recent years, as illustrated in Fig. 27. In 1976, it consisted of 8646 aircraft, of which over 90 percent were fixed-wing models. Almost 36 percent of these fixed-wing aircraft were types adapted to ag-air use rather than

---

*The term "productivity is used here to describe average annual area treated per aircraft. The term "utilization" will be used for average annual hours flown per aircraft. Both measures relate to average usage of the fleet rather than of specific airplanes.

FIG 25

UTILIZATION AND PRODUCTIVITY TRENDS IN US AG–AIR INDUSTRY



79–01–255–7

PRODUCTIVITY OF AG–AIRCRAFT IN US

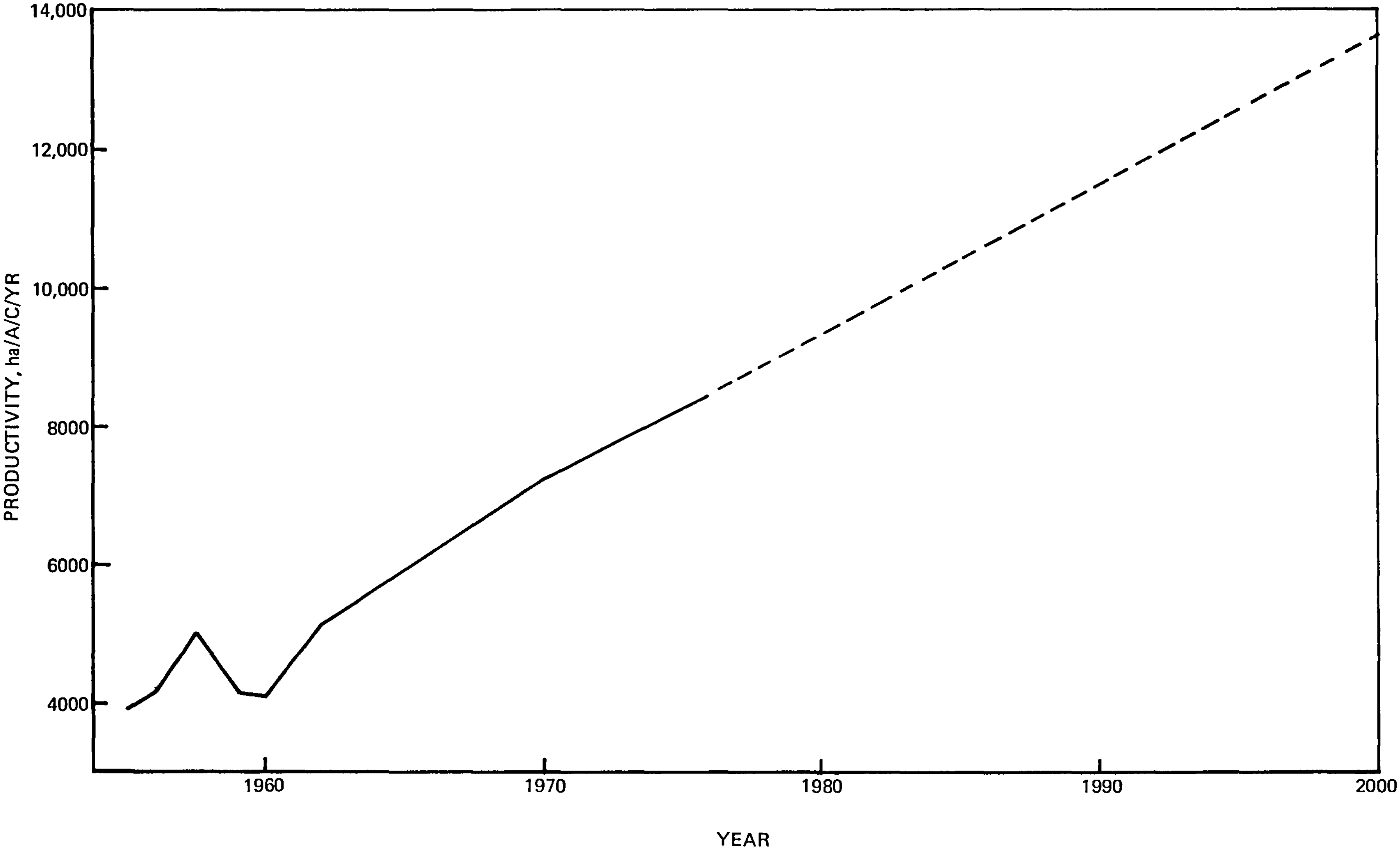
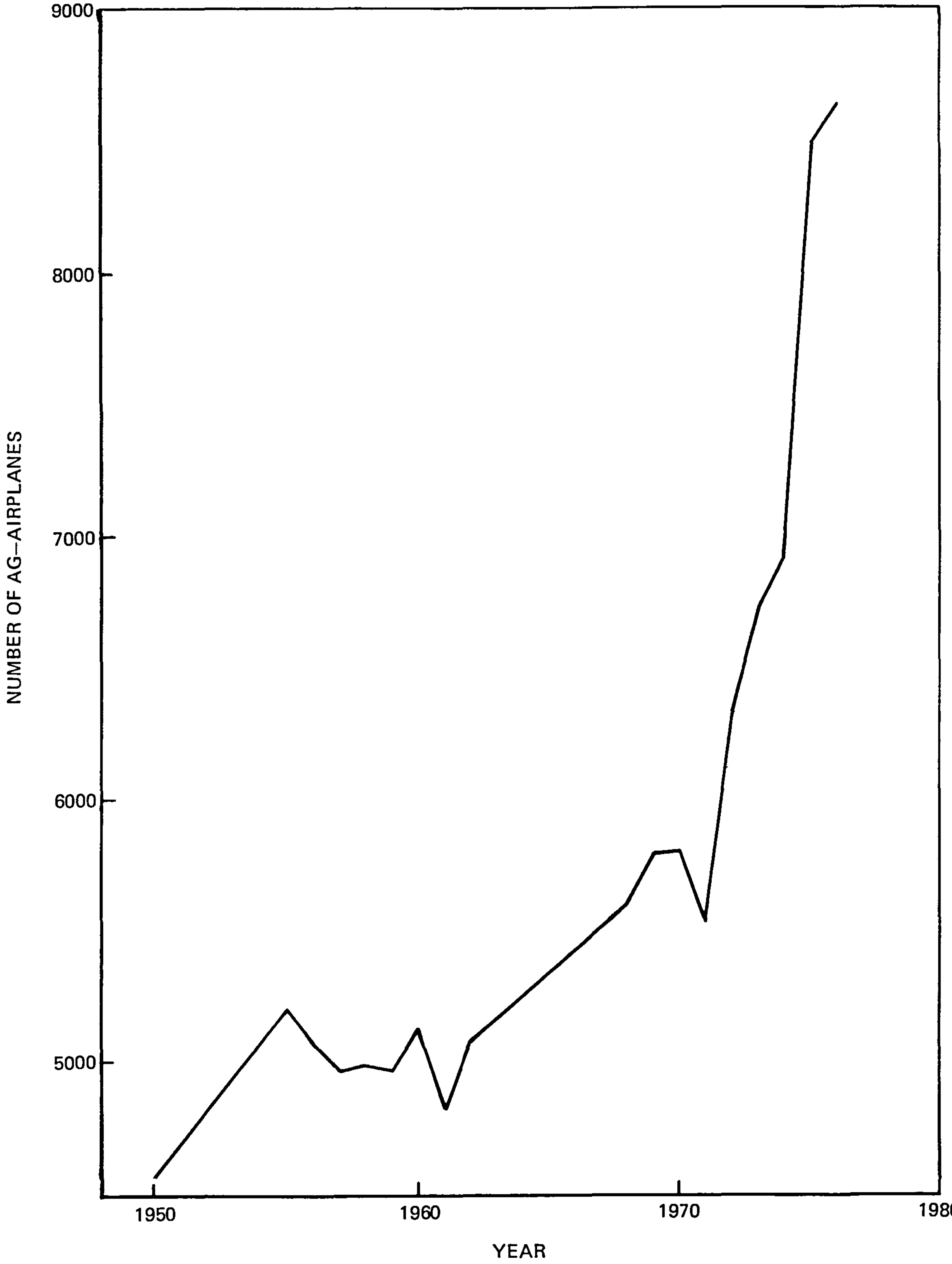


FIG 26

79–01–255–6

FIG 27

SIZE OF THE US AG–AIR FLEET



79–01–255–5

designed specifically for this type of operation. However, the rapid pace of recent deliveries is changing the character of the fleet, both in the representation of dedicated ag-models and in the increasing average size of airplanes. To illustrate, let the following categorization be used to describe small, medium, and large fixed-wing ag-aircraft.

Category	Normal Takeoff Weight (kg)	US Models
Small	Less than 1700	Pawnee, AgCarryall
Medium	1700 to 2700	AgWagon, AgTruck, Pawnee Brave
Large	Greater than 2700	Ag Cat, Thrush

Then, recent deliveries to US operators break down as shown in Fig. 28. It is apparent that deliveries of the small models have declined over the past decade and that the medium and large aircraft have approximately equal shares.

Despite these trends, the US fleet still consists primarily of small-size aircraft, as shown below.

Category	Fleet Number	Fleet Percent
Small		
Ag Models	1701	19.7
Other	2811	32.5
Total	4512	52.2
Medium	1519	17.6
Large	1807	20.9
Total fixed-wing	7838	90.7
Rotary wing	808	9.3
Total	8646	100.0

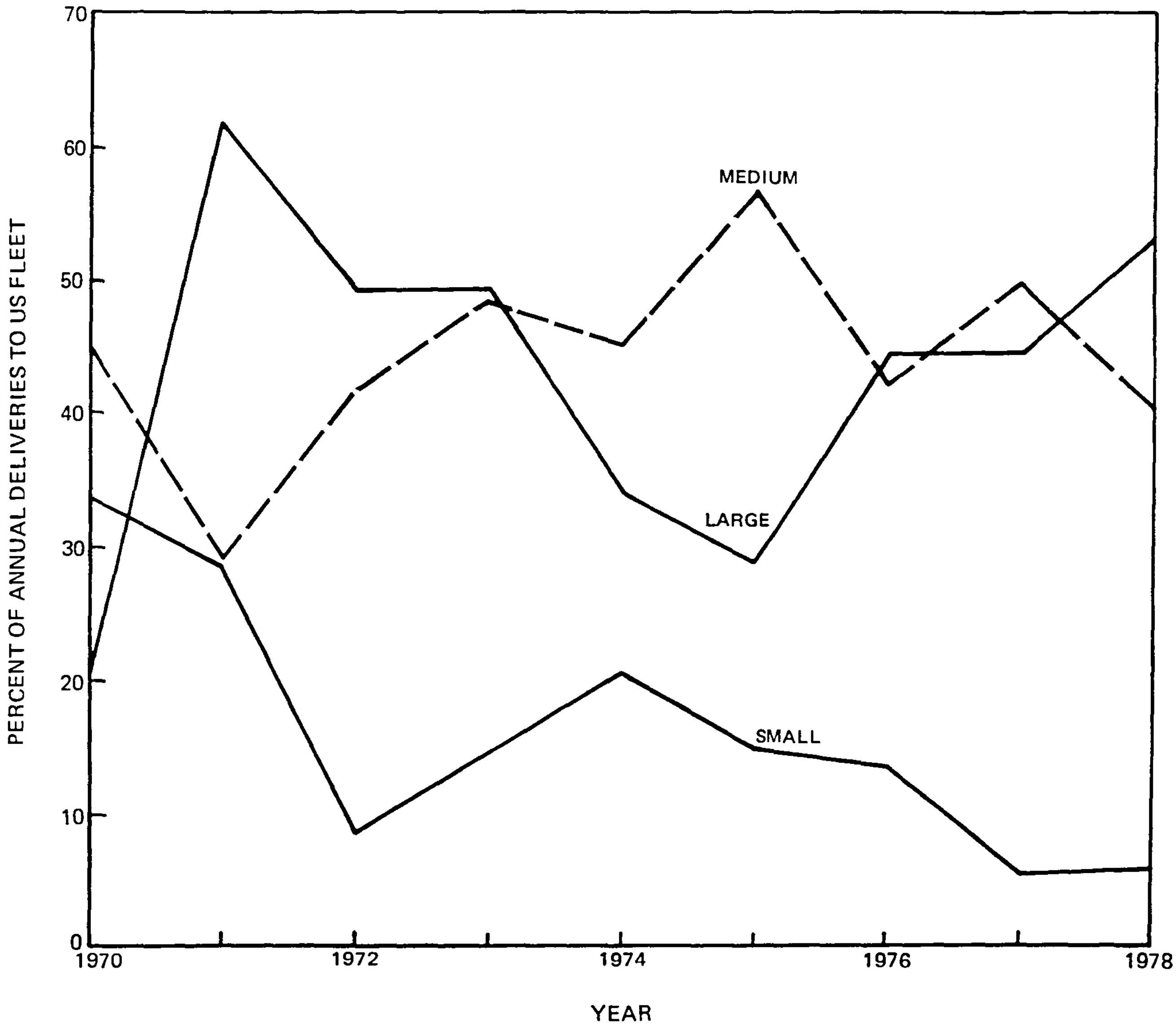
For the future, it is to be expected that the trends in Fig. 28 will continue, and that the following percentages may be assumed for shipments in the three fixed-wing categories.

Category	Period: 1975-1980	1980-1985	1985-1990	1990-1995	1995-2000
	Percent of Deliveries				
Small	5	2	0	0	0
Medium	50	49	48	46	44
Large	45	49	52	54	56

The percentage of rotary-wing aircraft in the US ag-air fleet has grown to almost 10 percent from less than 2 percent in 1960. It appears that the steady rise in helicopter use is both a reflection of recent trends in the

FIG. 28

CHANGING TRENDS IN DELIVERIES OF SMALL, MEDIUM, AND LARGE FIXED–WING AIRCRAFT TO US FLEET



79–01–255–12

industry (e.g., increased attention to drift control as environmental standards are tightened) and the growth of those sectors of the industry for which helicopters are uniquely adapted (e.g., orchard applications). These trends can be expected to continue -- environmental factors will escalate in importance (although drift control of fixed-wing applications may also improve as a result of improved technology and practice), and fairly high growth rates can be expected for the orchard and vegetable crops where helicopter uses are concentrated. Furthermore, tecnnology has improved helicopter characteristics, and technology and volume production have reduced cost escalation. Therefore, the projection in Fig. 29 for continued growth in the rotary-wing component of the fleet has been adopted*.

Attrition

An accurate estimate of the rate of attrition in the ag-air fleet could be made only if the fleet data itself were perfectly accurate and consistent from year to year. In fact, the historical US fleet data, while the best in the world, are not entirely complete and consistent, making the analysis of fleet attrition difficult. Part of the difficulty comes from incomplete reporting of aircraft, and part is a result of the presence of some multipurpose aircraft which may be used only part-time for agricultural purposes. If errors induced by this accounting could be filtered out, then only the desired reasons for attrition would be represented by the data, namely, destruction of aircraft by accidents and removal from the fleet due to obsolescence (economic, technical, or safety factors).

To obtain the best possible estimate of attrition, US fixed-wing fleet and shipment data were analyzed for the 1960-to-1976 period. If post-1960 shipments are added to the 1960 fleet, as in Fig. 30, then fleet growth should have proceeded according to the upper line. The actual fleet history is shown to be well below this line, the difference apparently representing attrition, although the inaccuracies noted earlier cause some uncertainty.

The average growth rate of the upper line in Fig. 30 is 6.0 percent/yr and the average growth rate of the fleet line is 2.8 percent/yr. Therefore, attrition apparently averaged 3.2 percent/yr during the period shown**. Since there is room for error in this estimate, a similar calculation was made for the entire US general aviation fleet, for which data are more credible. The attrition rate in that fleet was calculated to be 1.3 percent/yr,

*Note that most other developed nations' fleets have larger rotary-wing components than the US: USSR - 25 percent, Oceania - 20 percent, Japan - 100 percent, France - 71 percent, UK - 40 percent.

**Note that this attrition rate cannot be directly converted to an estimate of average useful life of an airplane. It can be used only to determine that percent of the fleet which can be expected to be removed in the coming year.

ROTARY WING COMPONENT OF US AG–AIR FLEET

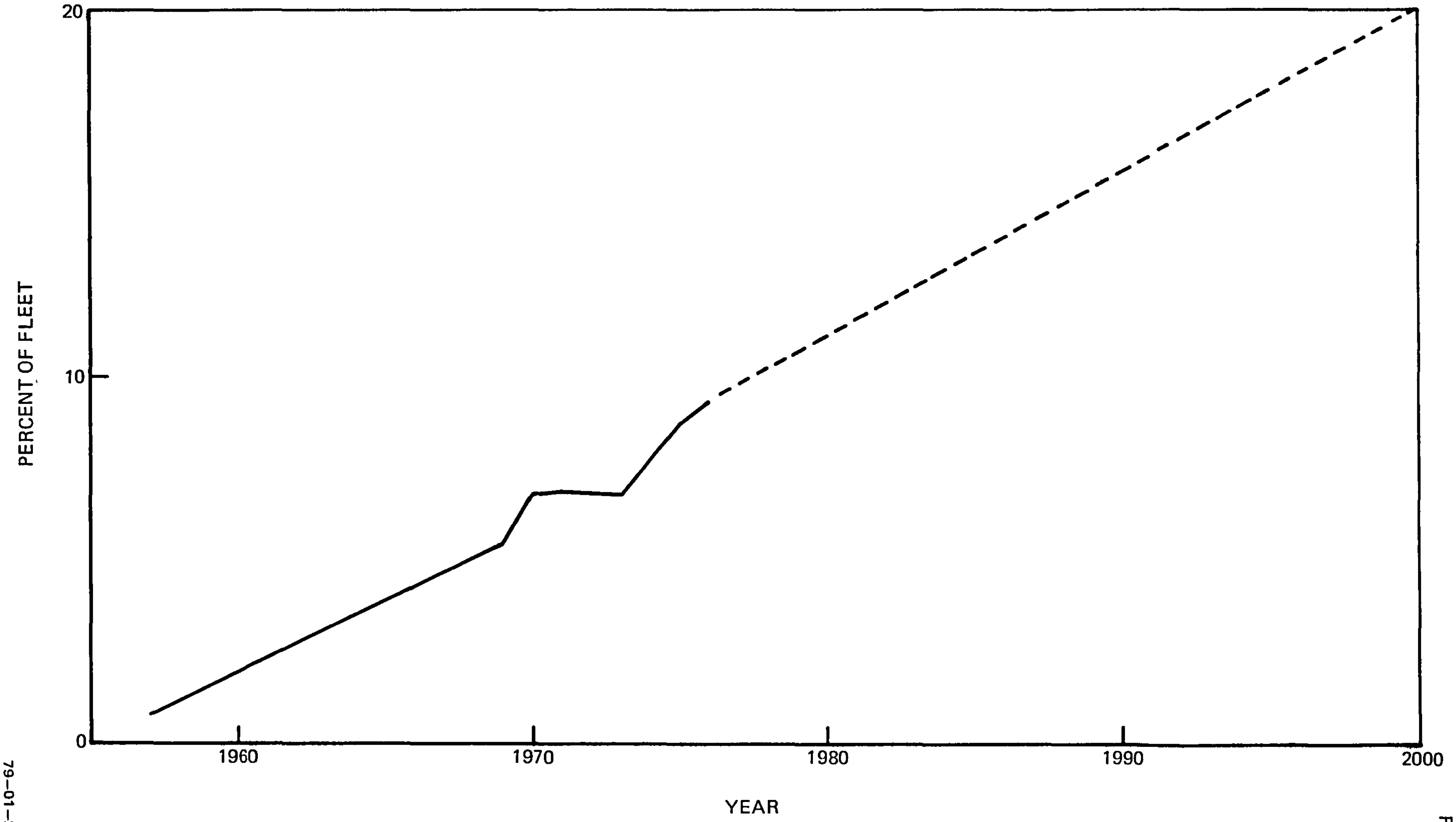


FIG 29

79–01–255–13

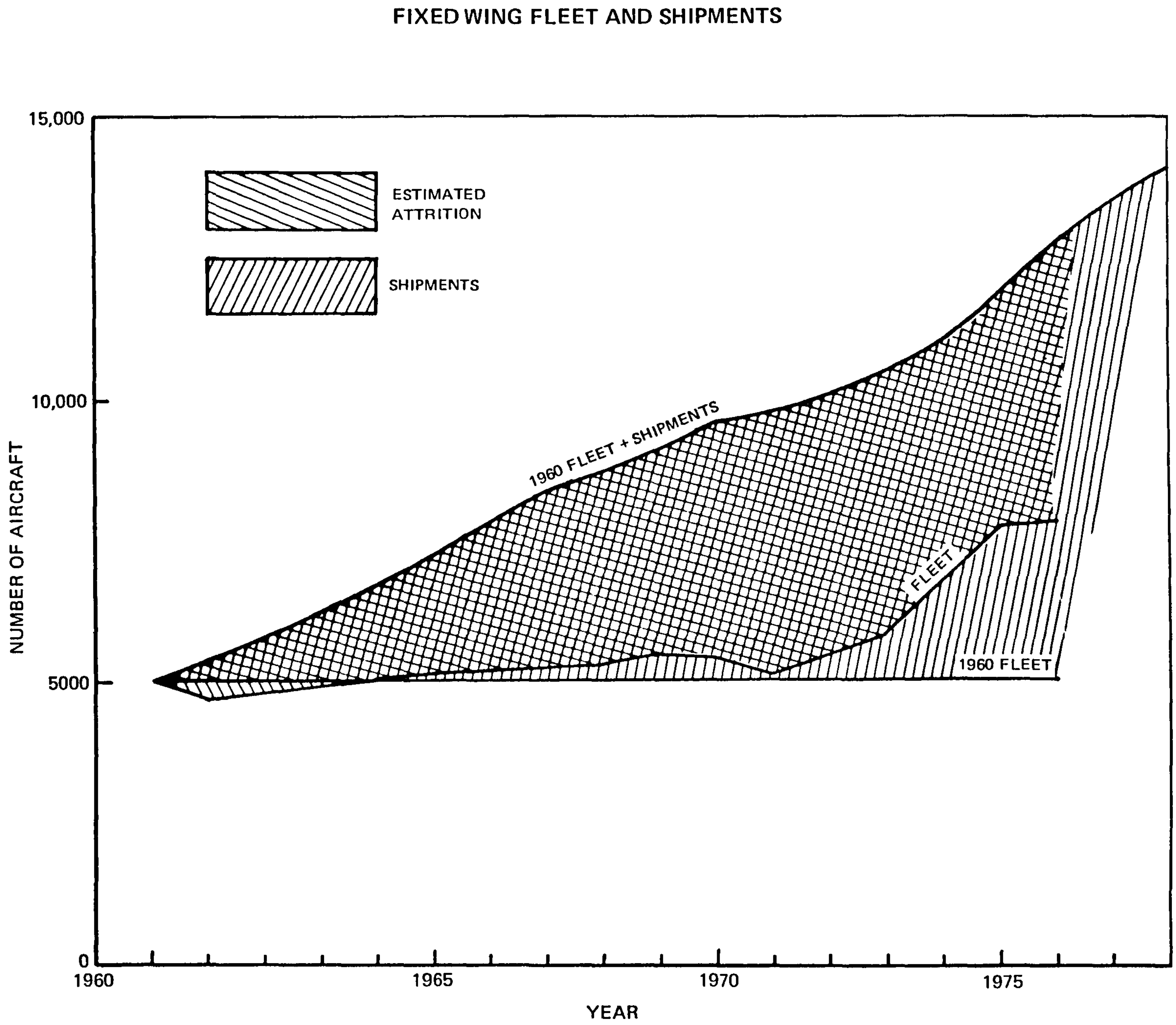


FIG 30

79–01–255–8

less than half the ag-air figure. Although the ag-air rate is presently high, it is likely to decrease in the future as the older models which were adapted to agriculatural use in the early years of the industry are retired from service. Also, improvements in handling qualities and piloting skill will further reduce attrition. Therefore, a rate of 2.5 percent/yr was adopted in the projections for dedicated ag-airplanes and helicopters, and 3.2 percent/yr for other models.

Fleet Projection

With the nominal fleet composition, productivity, and attrition assumptions described above, and the projection of treated area in Fig. 24, estimates of US fleet requirements were made in five-year periods to the year 2000. The results are shown in Fig. 31, along with historical data in the same format. Whereas various aircraft converted to agricultural use ("other " in Fig. 31) dominated the industry prior to 1960, the numbers of these aircraft have diminished steadily since that time and now constitute only about 30 percent of the fleet. Continued attrition of these airplanes at the assumed 3.2 percent/yr rate will further reduce their numbers in the forecast period so that, by 2000, they will comprise only a little more than 6 percent of the fleet.

Aircraft in the "Small" category, which includes all dedicated ag-aircraft with take-off weights under 1700kg, grew in numbers throughout the 1960s, but deliveries of these models to US operators have declined in recent years and a further contraction of that fleet is forecast. By 2000, it is projected that only 5.5 percent of the fleet will consist of these small ag-aircraft.

Strong future growth is predicted for both medium- and large-size ag-models. Recent expansion of these fleets has brought them to almost 40 percent of the total fleet, and almost a doubling of that level is forecast by 2000. Note that the size designations used here allow for unlimited growth in the "Large" category (over 2700 kg takeoff weight). Therefore, introduction of new models, larger than the Ag Cat and the Thrush, would not affect these results. A new medium-size aircraft or a derivative of existing models in this class might also be introduced. However, it is assumed that no new aircraft in the "Small" category will be purchased by US operators, although such an aircraft might be attractive to operators in foreign countries.

Projected World Market

Projections for other world regions were made in an analogous way to that described for the US market, namely, by making estimates for treated area, productivity, fleet composition, and attrition. Estimates for treated area were made for each of 17 world regions and then aggregated into three groups: developed nations (including the USSR), developing countries, and a

NOMINAL PROJECTION OF US AGRICULTURAL AIRCRAFT FLEET

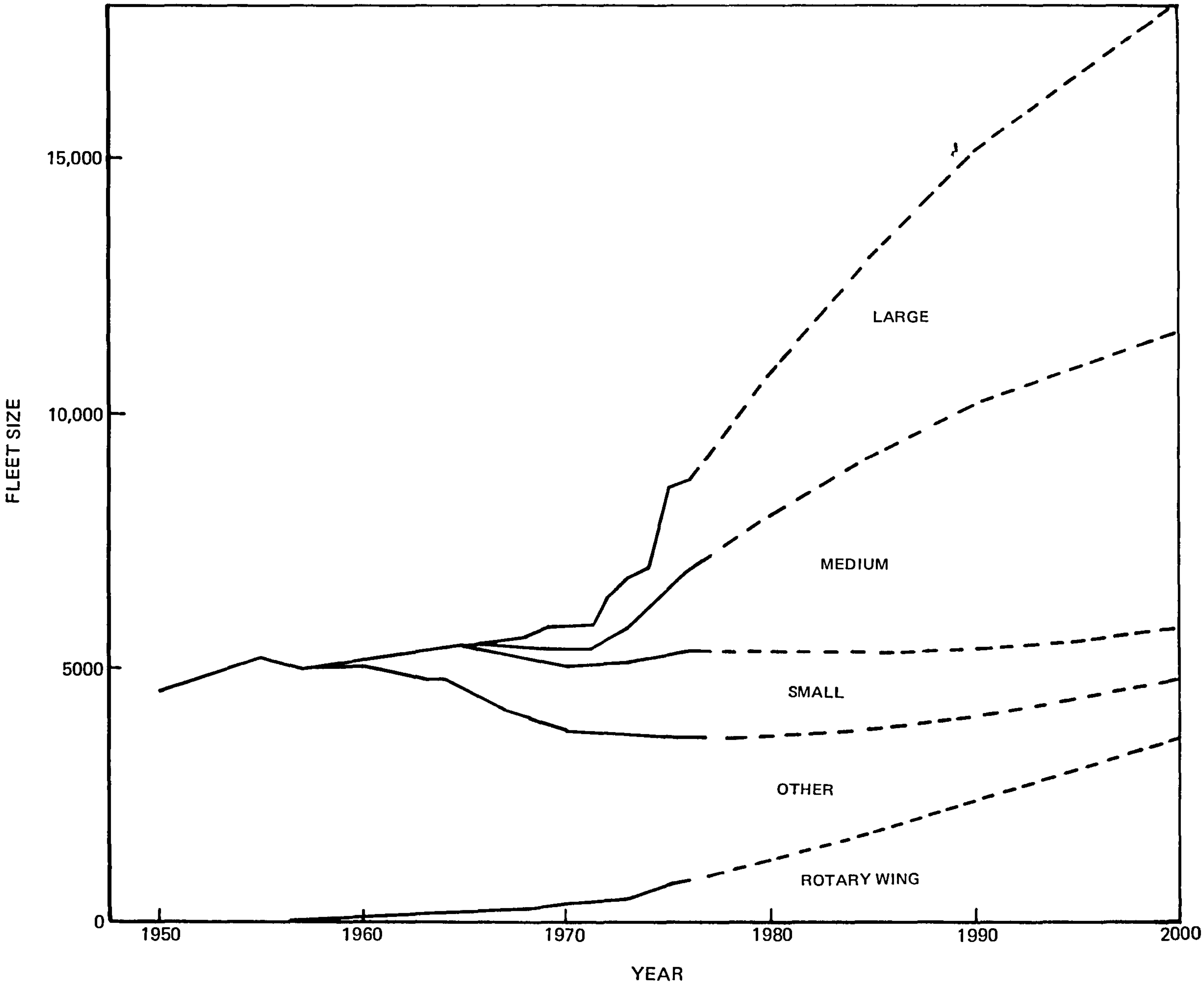


FIG 31

79-01-255-4

third group which consists primarily of communist nations other than the USSR. The other parameters were estimated only for the three major groups, although data for particular nations in each group were used as the basis for making the estimates.

Treated Area

Projections of treated area were made using the scaling factors in Table 5 for each crop and then correcting the calculated values according to the field size criterion (ratio of calculated to actual area) in Table 6. This process began, as for the US, with projections of production for each crop. A complete summary by region is provided in the Appendix. Aggregations of these data into the three major world groups appear in Tables 8 to 10, followed by a full aggregation to the world level in Table 11 and Fig. 32. The tables show the average production in the 1974-1976 period, the average growth rate of production (as determined from the 1961-1976 period), the forecasted production in the year 2000, and conversions of both sets of production volumes to treated area. Some important trends can be derived from these tabulations. For example, the developed-nation group is clearly dominant, and will be even more dominant in the future, as shown by the following summary by major regions.

Region	Treated Area, 10^6 ha 1975	Treated Area, 10^6 ha 2000	Growth Rate %/yr
Developed	185.0	570.5	4.6
LDC	37.2	92.1	3.7
Other	9.7	42.1	6.1
World	231.9	704.7	4.6

However, since the US and the USSR account for a large fraction of the developed-nation group, the following summary is also revealing.

Region	Treated Area, 10^6 ha 1975	Treated Area, 10^6 ha 2000	Growth Rate %/yr
US	71.6	262.0	5.3
USSR	91.0	236.4	3.9
Other Dev'd	22.4	72.1	4.8
All Dev'd	185.0	570.5	4.6

These results show that the US will be the fastest-growing market in the world, overtaking the USSR in area treated before the end of the century.

Considering the results in Table 11, with respect to crops, it is apparent that cotton will remain an important ag-air crop, but that rice will become the recipient of the greatest ag-air activity, and that grains, collectively, will account for most ag-air activity.

TABLE 8

PROJECTIONS FOR DEVELOPED NATIONS
Includes USSR

Crop Category	Production			Treated Area		
	1974-76 Av. Prod. 10^9 kg	Avg. Gr. Rate %/yr	2000 Prod. 10^9 kg	1975 Area 10^6 ha	2000 Area 10^6 ha	Avg. Gr. Rate %/yr
Wheat	220.2	2.8	438.8	18.2	49.9	4.1
Rice	25.0	3.5	59.5	20.7	113.6	7.1
Corn	187.1	3.6	455.6	4.8	19.4	5.7
Sorghum	19.9	3.6	48.6	4.8	17.8	5.4
Roots	155.1	-0.3	145.3	13.2	16.4	0.9
Dry Beans	3.3	0.7	3.9	5.1	8.7	2.1
Soybeans	49.2	3.9	128.4	6.3	29.4	6.3
Other Grains	123.6	6.2	558.1	21.5	105.8	6.6
Nuts	3.3	4.2	9.4	1.6	9.6	7.3
Sugar	260.4	2.8	525.0	2.2	4.9	3.2
Cotton	19.8	3.0	41.4	51.2	122.4	3.5
Vegetables	106.7	1.5	153.2	12.3	27.5	3.2
Citrus	23.1	3.1	127.9	1.9	13.4	4.5
Other Fruit	75.8	7.1	163.6	1.6	4.9	8.2
Tobacco	2.0	2.1	3.3	0.5	1.1	3.1
Timber*	7.20	-0.8	5.88	1.1	1.7	1.6
Rangeland*	812	0.6	932	13.9	19.5	1.4
Area Insects*	1841	0.1	1891	3.7	4.6	0.8
TOTAL				185.0	570.5	4.6

* In units indicated in Table 5

TABLE 9

PROJECTIONS FOR LDC GROUP

Crop Category	Production			Treated Area		
	1974-76 Av. Prod. 10^9 kg	Avg. Gr. Rate %/yr	2000 Prod. 10^9 kg	1975 Area 10^6 ha	2000 Area 10^6 ha	Avg. Gr. Rate %/yr
Wheat	90.4	5.0	304.5	1.1	2.9	3.9
Rice	180.1	2.6	339.9	9.8	22.6	3.4
Corn	76.1	3.2	169.2	0.5	0.9	2.5
Sorghum	31.2	8.2	224.6	1.5	21.4	11.3
Roots	175.7	2.5	324.6	1.7	2.7	1.9
Dry Beans	15.5	1.7	23.6	5.0	7.4	1.6
Soybeans	30.0	7.1	166.8	0.6	3.4	7.3
Other Grains	48.9	3.6	117.4	1.0	3.1	4.6
Nuts	18.0	1.3	24.5	0.5	0.7	1.0
Sugar	522.9	3.5	1226.2	0.9	1.8	2.8
Cotton	24.2	1.6	36.6	6.9	9.0	1.1
Vegetables	114.7	3.1	248.0	1.9	5.5	4.3
Citrus	24.6	6.2	111.9	0.7	3.1	3.1
Other Fruit	116.2	2.7	226.9	0.7	1.5	6.4
Tobacco	3.3	2.5	6.1	0.1	0.2	3.4
Timber*	3.07	1.7	4.63	0.1	0.1	0.5
Rangeland*	1136	1.2	1513	3.6	5.1	1.4
Area Insects*	2288	0.5	2579	0.7	0.7	0.4
TOTAL				37.2	92.1	3.7

* In units indicated in Table 5

TABLE 10

PROJECTIONS FOR OTHER COMMUNIST NATIONS

	Production			Treated Area		
Crop Category	1974-76 Av. Prod. 10^9 kg	Avg. Gr. Rate %/yr	2000 Prod. 10^9 kg	1975 Area 10^6 ha	2000 Area 10^6 ha	Avg. Gr. Rate %/yr
Wheat	67.1	5.1	232.7	0.7	6.2	8.9
Rice	116.4	2.5	217.4	1.6	7.4	6.2
Corn	52.1	3.6	126.6	0.2	1.1	8.1
Sorghum	0.1	13.6	1.4	~ 0	~ 0	7.4
Roots	221.4	2.1	375.1	2.1	5.2	3.6
Dry Beans	6.8	4.4	19.8	0.3	0.6	3.0
Soybeans	17.4	2.8	34.7	~ 0	0.4	11.9
Other Grains	37.4	3.1	80.6	1.0	11.2	10.2
Nuts	3.3	3.1	7.0	~ 0	0.1	1.9
Sugar	144.4	3.7	359.7	1.5	1.5	2.8
Cotton	11.3	6.3	52.6	0.3	0.9	4.5
Vegetables	83.2	2.2	143.3	1.1	1.9	2.4
Citrus	1.5	2.7	5.5	0.1	0.6	5.8
Other Fruit	14.0	5.4	27.4	~ 0	0.1	5.8
Tobacco	1.7	3.5	4.1	~ 0	0.2	5.0
Timber*	6.41	4.8	20.94	0.8	3.5	6.3
Rangeland*	204	0.8	249	0.5	1.1	3.5
Area Insects*	409	0.5	469	~ 0	0.1	3.4
TOTAL				9.7	42.1	6.1

* In units indicated in Table 5

TABLE 11

PROJECTIONS FOR WORLD

	Production			Treated Area		
Crop Category	1974-76 Av. Prod. 10^9 kg	Avg. Gr. Rate %/yr	2000 Prod. 10^9 kg	1975 Area 10^6 ha	2000 Area 10^6 ha	Avg. Gr. Rate %/yr
Wheat	377.7	3.9	975.9	20.0	59.1	4.4
Rice	321.5	3.0	616.8	32.1	143.6	6.2
Corn	315.2	3.5	751.4	5.4	21.3	5.6
Sorghum	51.1	7.2	274.6	6.3	39.2	7.6
Roots	552.2	1.7	845.0	17.1	24.2	1.4
Dry Beans	25.7	2.5	47.4	10.4	16.7	1.9
Soybeans	96.6	5.0	329.9	6.9	33.3	6.5
Other Grains	209.8	5.3	765.2	23.5	120.0	6.7
Nuts	24.6	2.1	41.0	2.2	10.3	6.4
Sugar	927.6	3.3	2110.8	3.9	8.3	3.0
Cotton	55.4	3.6	130.7	58.5	132.3	3.3
Vegetables	304.6	2.4	544.5	15.4	34.9	3.4
Citrus	49.2	6.6	245.3	2.6	16.6	7.8
Other Fruit	206.0	2.9	417.8	2.5	6.9	4.2
Tobacco	7.0	2.7	13.5	0.7	1.5	3.3
Timber*	16.68	2.6	31.45	2.0	5.3	4.0
Rangeland*	2151	0.9	2693	18.0	25.7	1.4
Area Insects*	4538	0.3	4939	4.4	5.4	0.8
TOTAL				231.9	704.7	4.6

* In units indicated in Table 5

HISTORICAL AND PROJECTED TRENDS FOR TREATED AREA

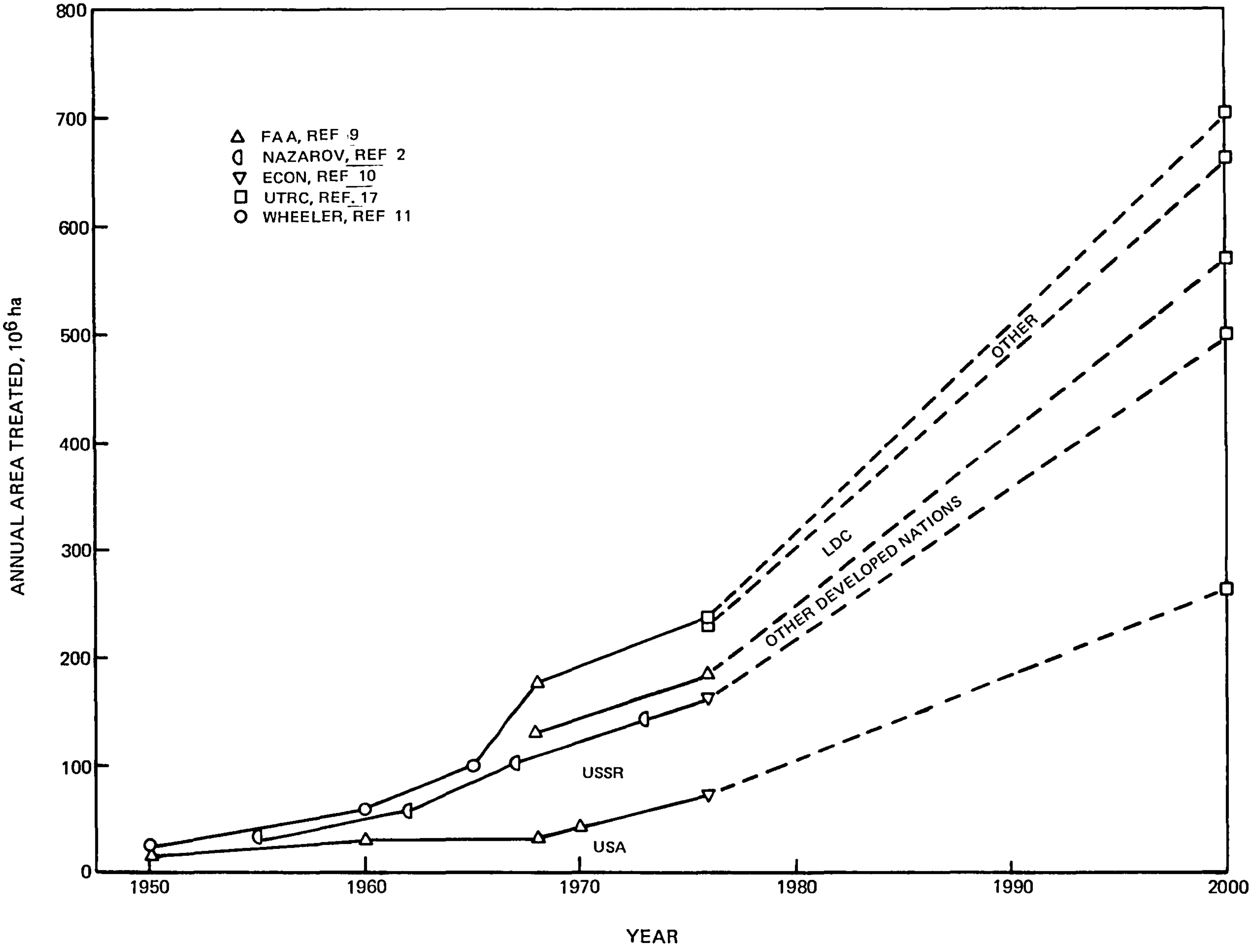


FIG 32

79–01–255–10

Crop	Treated Area, 10^6 ha 1975	2000	Growth Rate %/yr
Rice	32.1	143.6	6.2
All Other Grains	55.2	239.6	6.0
Cotton	58.5	132.3	3.3

If the crop categories are aggregated into larger units, the importance of grains relative to other crops is very evident.

	Category	Treated Area, 10^6 ha 1975	2000	Growth Rate %/yr
Field Crops	Grains	87.3	383.2	6.1
	Veg., Fruits & Nuts	20.5	58.4	4.3
	Other Edibles	40.5	92.8	3.4
	Inedibles	59.2	133.8	3.3
Noncrop Uses		24.4	36.4	1.6
	Total	231.9	704.7	4.5

Whereas grains accounted for 38 percent of treated area in 1975, that figure will increase to 54 percent by 2000, with 20 percent of the activity in rice alone. Inedible field crops (cotton and tobacco) go from 26 percent to 19 percent in the 25-year period.

Finally, it is of interest to identify the high-and low-growth crop categories, independently of absolute activity.

	Crop	Growth Rate %/yr
High Growth:	Citrus	7.8
	Sorghum	7.6
	Other Grains	6.7
	Soybeans	6.5
	Nuts	6.4
	Rice	6.2
Low Growth:	Area Insect Control	0.8
	Rangeland	1.4
	Roots	1.4
	Dry Beans	1.9

The area insect category may be understated in these projections because this type of activity is not as common in the US as in Africa and Asia, and the US is the primary base for the scaling laws. Long-term insect eradication programs are presently in progress, or planned, for control of flies and mosquitoes which are most prevalent in the tropics (Refs. 29-31). Although these programs will involve large areas over a period of many years, the aircraft utilized in this type of spraying are usually not of the ag-air variety, various general aviation and surplus military models often being mobilized for this purpose. Therefore, a low estimate of area treated in this category would not affect the goals of this study to the same extent as an understatement with respect to one of the important field crops.

Productivity

It was shown in Fig. 26 that the productivity (ha/yr/aircraft) of the US fleet has been advancing steadily, but that there is still considerable room for future improvement. Estimates of fleet productivity changes for other world regions are difficult to make with any precision because such estimates require fairly accurate knowledge of both fleet size and area treated for a period of years. Based on 1970 data, it appears that most values for fleet productivity fall within a fairly narrow range.

	Major World Regions					
	US	USSR	Other Dev. Nations	LDCs	Other Comm.	World
Treated Area, 10^6 ha	72.8	91.0	22.4	37.2	11.5	234.9
Fleet Size	8650	10,000	2500	3850	1000	26,000
Productivity, ha/aircraft	8400	9100	9000	9700	11,500	8900

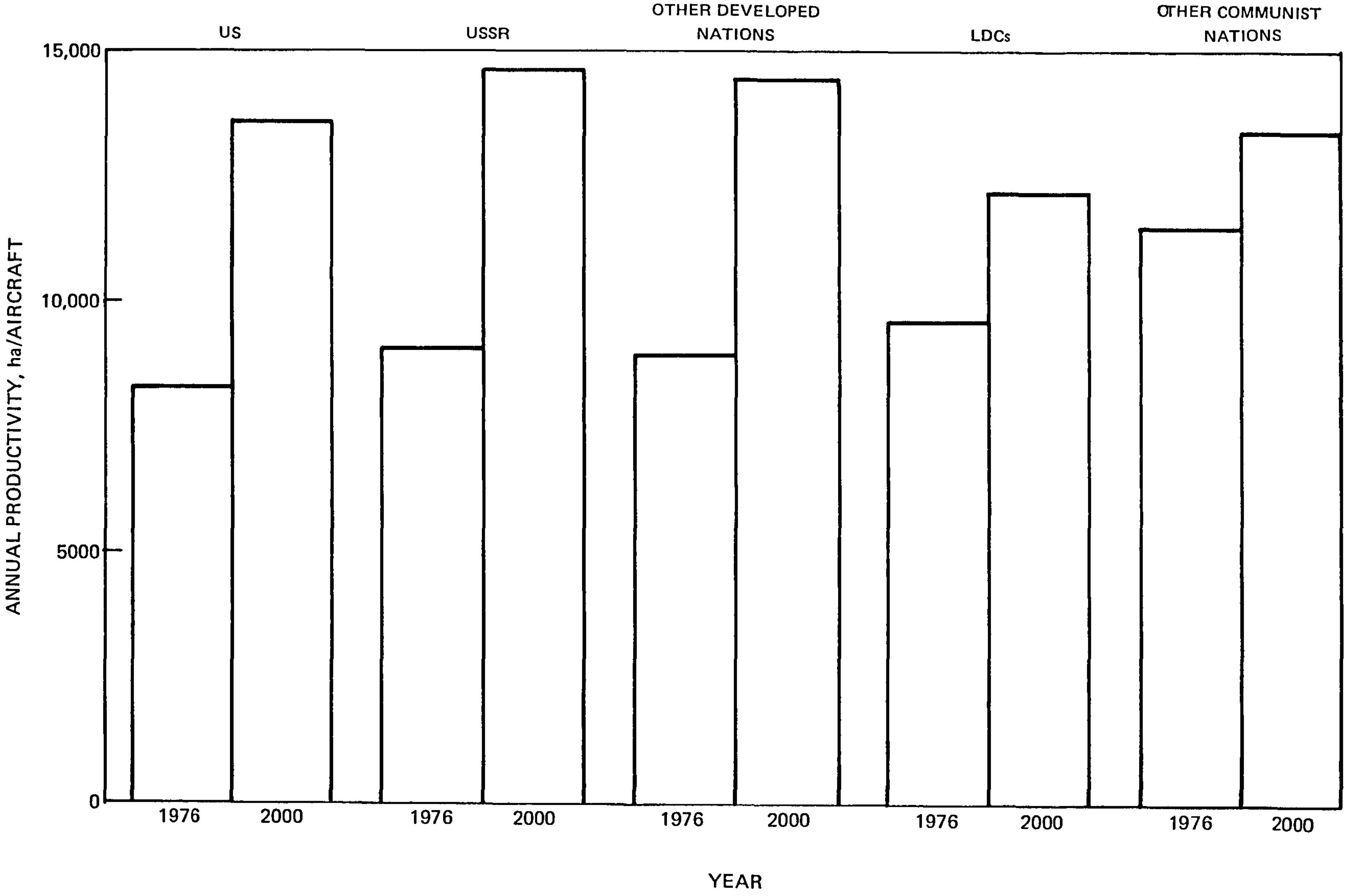
Earlier data suggest that productivity decreased somewhat in most regions during the 1960s, although lack of hard data makes such evidence inconclusive. Therefore, nominal growth rates similar to US projections have been adopted, i.e., 2 percent/yr for developed countries and 1 percent for others. The results by region are depicted in Fig. 33.

Fleet Composition

A summary of fleet information for representative nations in most world regions is provided in Table 12, showing the breakdown between rotary- and fixed-wing (FW) models in each fleet and the breakdowns (where available) of the fixed-wing fleets by aircraft size. When these data are aggregated into major world regions, some interesting observations can be made.

	US	USSR		Other Dev. Nations	LDCs	Other Communist	
Rotary Wing, %	9.3	25.0		18.6	8.3	2.0	
Fixed Wing, %	90.7	75.0		81.4	91.7	98.0	
Small, % of FW	58	10	(est.)	44	46	20	(est.)
Medium, % of FW	19	10	(est.)	44	50	50	(est.)
Large, % of FW	23	80	(est.)	12	4	30	(est.)

AG–AIRCRAFT PRODUCTIVITY PROJECTIONS BY MAJOR WORLD REGION



79–01–255–23

FIG 33

TABLE 12

BREAKDOWN OF FLEETS IN VARIOUS COUNTRIES

Region	Country	Year	Number of Aircraft				Percent of Fixed-Wing		
			Rotary	Fixed-Wing					
			Wing	Ag	Other	Total	Small	Medium	Large
North America	US	1976	808	5027	2811	8646	57.6	19.4	23.0
	Canada	1971	30	95	245	370	-	-	-
Oceania	Australia	1976	1	194	51	246	44.9	34,7	20,4
	New Zealand	1976	137	216	98	451	36.9	21.1	42,0
Western Europe	France	1976	64	19	7	90	57.7	34.6	7.7
	UK	1968	46	67	3	116	75.7	12.9	11.4
Japan	-	1976	173	0	0	173	-	-	-
South Africa	-	1968	0	104	17	121	49.6	14.9	35.5
USSR	-	1976	2500	-	-	10,000	-	-	-
Israel	-	1968	11	49	3	63	23.1	-	76,9
Trop. Lat. America	Colombia	1976	11	127	83	221	47.1	49.6	3.3
	Brazil	1968	0	45	174	219	79.5	16.4	4.1
	Brazil	1976	4	221	8	233	18.4	76.8	4.8
Temp. Lat. America	Chile	1976	3	27	11	41	68.4	31.6	0
Asia	India	1976	29	-	-	70	-	-	-
Eastern Europe	Yugoslavia	1976	0	27	19	46	26.1	0	73.9

Among the developed-nation groups, the US has the smallest rotary-wing fleet component. The USSR operates a large fleet of helicopters (Ref. 2) for a variety of uses, and some developed nations, e.g., Japan, rely exclusively on helicopters for agricultural work.* The US rotary-wing fleet component was projected in Fig. 29 to grow at a rate of about 3 percent/yr to a value of 20 percent of the fleet in the year 2000. Less-developed country fleets are expected to grow at the same rate, but other developed nations, including the USSR, will experience a somewhat slower growth of 1.5 percent/yr. The following table summarizes these projections.

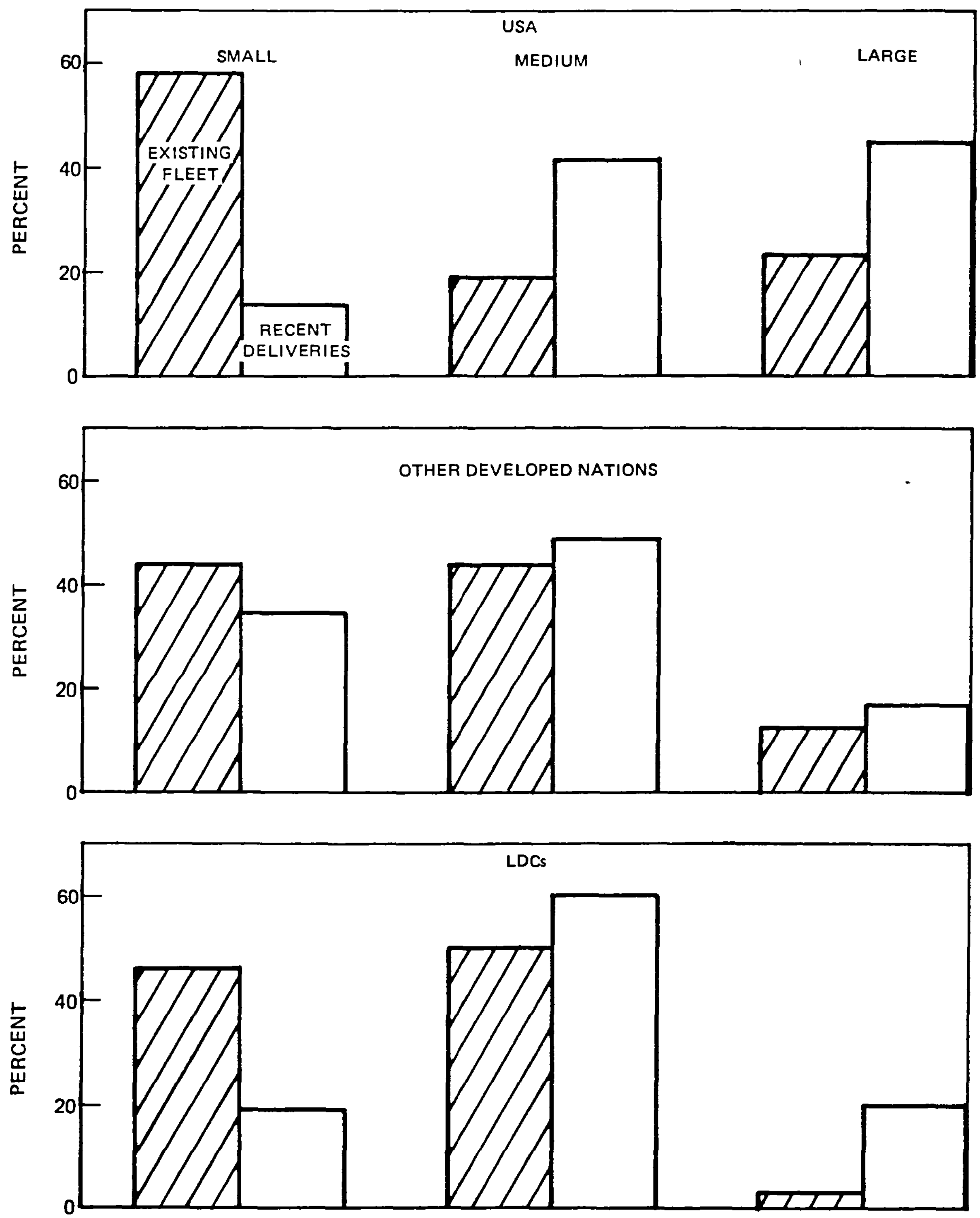
	Percent Rotary Wing	
	1976	2000
US	9.3	20.1
USSR	25.0	35.7
Other Dev. Nations	18.6	26.6
LDCs	8.3	17.9
Other Comm.	2.0	4.3

Less information is available on the size categories of fixed-wing aircraft operating in each region, and no information was obtained for the communist nations. However, it is probable that most of the aircraft in the USSR fleet would fall into the large- and medium-size categories and that, on the basis of types produced in Eastern Europe, the medium class would dominate in the Other Communist group. The statistics for the Other Developed Nations group are strongly influenced by Oceania, whereas the LDC group is strongly influenced by Latin America. The fleets in these regions are split almost evenly between the small and medium categories, with a much smaller percentage of large models presently operating. On the other hand, the US fleet consists of a majority of small aircraft (many of these being older models), but with a good representation of large aircraft.

Recent deliveries show a somewhat different picture, particularly in the US and the LDC group. A comparison of the present fixed-wing fleet components with delivery data for the 1975-to-1978 period is given in Fig. 34. This figure demonstrates that a shift toward larger aircraft is underway in each of the regions shown. In all cases, the percentage of deliveries in the medium- and large-categories exceeds the corresponding percentage of the present fleet; reductions in the percentages of small aircraft are the obvious results of these trends. Therefore, the trends in Table 13 were established to describe the breakdown of deliveries in five-year intervals during the forecast period. They describe a continuation of the trend toward fewer small aircraft deliveries, with differing emphases on the medium and large classes depending on the region. The rates of growth in these projections are influenced by farm holding trends (Table 6) as well as the recent experience shown in Fig. 34.

*There have been some recent deliveries of fixed-wing aircraft to Japan.

FIXED–WING AG–AIRCRAFT SIZE TRENDS



79–01–255–30

TABLE 13

PROJECTION OF FUTURE FIXED-WING DELIVERIES

Time Period	Size* Category	Percent of Deliveries				
		US	USSR	Other Dev. Nations	LDCs	Other Comm.
1975-1980	S	5	0	34	19	20
	M	50	20	49	61	50
	L	45	80	17	20	30
1980-1985	S	2	0	30	11	18
	M	49	10	51	61	50
	L	49	90	19	28	32
1985-1990	S	0	0	26	2	16
	M	48	0	53	62	50
	L	52	100	21	36	34
1990-1995	S	0	0	22	0	14
	M	46	0	55	56	50
	L	54	100	23	44	36
1995-2000	S	0	0	18	0	12
	M	44	0	57	48	50
	L	56	100	25	52	38

* S = Small
M = Medium
L = Large

Attrition

As noted earlier, even US data do not provide a firm basis for estimating ag-air attrition rates, although a good case was made for adopting a figure of 2.5 percent/yr for dedicated ag-air models compared to 3.2 percent/yr for the various other airplanes in the US fleet. In the absence of any comparable data on which to base different estimates, these same figures were also adopted for the other world regions.

Nominal World Fleet Projections

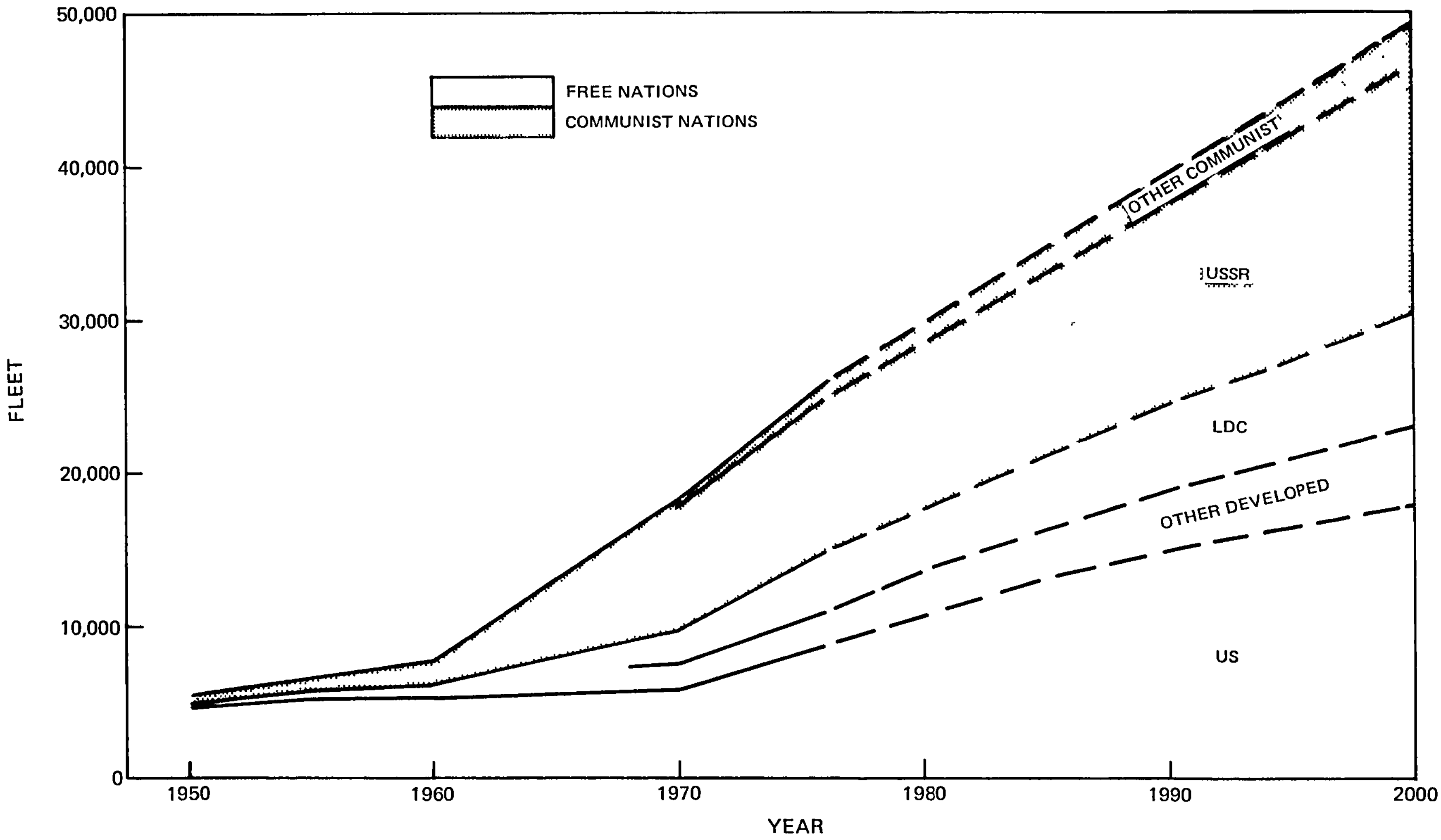
Applying the treated area, productivity, fleet composition and attrition estimates by major world region, a complete projection of the ag-air fleet was made to the year 2000. As described previously for the US market, these projections were made in five-year periods, beginning with 1975. Summaries of the results appear in Fig. 35, which shows the regional breakdown of the fleet, and in Fig. 36, which shows the fleet breakdown by type. Since the emphasis in this study was on markets accessible to US manufacturers, both these charts differentiate between the free and communist nations. Although the USSR market is quite large, it is not expected that US manufacturers will penetrate it in the foreseeable future. Close ties between the USSR and the Eastern European nations, which are very active in ag-aircraft manufacture, are likely to prevent US manufacturers from entering this lucrative market. Growth of the ag-air fleet is somewhat lower than the growth of treated area shown in Fig. 32 because of expected productivity gains and because of the evolutionary changeover to larger aircraft.

The US will continue to operate more than half the airplanes in the free-world fleet, even though a significant increase in the fraction of medium and large aircraft will occur (Fig. 31). For the free-world group, Fig. 36 shows that the percentage of large fixed-wing aircraft will increase from 14 percent in 1976 to 29 percent in 2000. In the same period, the medium fixed-wing percentage will increase from 27 percent to 36 percent and the rotary wing percentage will increase from 11 percent to 21 percent.

In the Communist group, which Fig. 35 shows to be quite dominated by the USSR, small- and medium-size fixed-wing aircraft play a minor role compared to large fixed-wing and rotary-wing aircraft. Therefore, by 2000, large fixed-wing and rotary-wing aircraft will account for almost 40 percent of the world fleet.

Of particular interest, from the standpoint of new aircraft technology, is the expected number of aircraft shipments during the forecast period. Figures 37 and 38 present the forecast of shipments with respect to region and type of aircraft, respectively. Also shown are some historical data for the 1961 to 1975 period. Some of these historical data were derived from actual shipment statistics in Table 4, but it was also necessary to back-calculate part of the data from fleet and attrition estimates given previously.

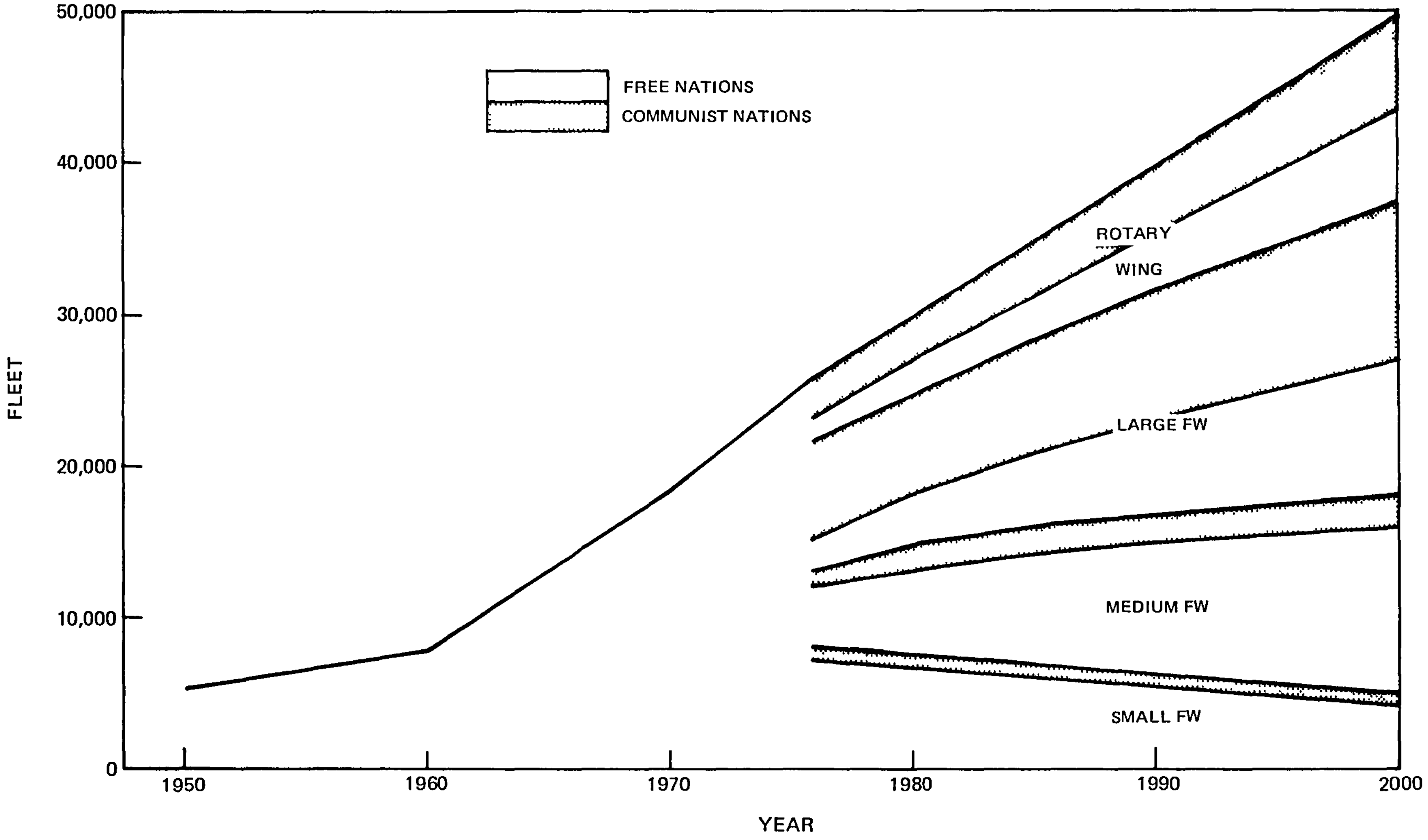
NOMINAL PROJECTION OF WORLD AG—AIR FLEET



79-01-255-17

FIG 35

NOMINAL WORLD AG–AIR FLEET BREAKDOWN



79–01–255–16

FIG 36

NOMINAL PROJECTION OF AG–AIR SHIPMENTS BY REGION

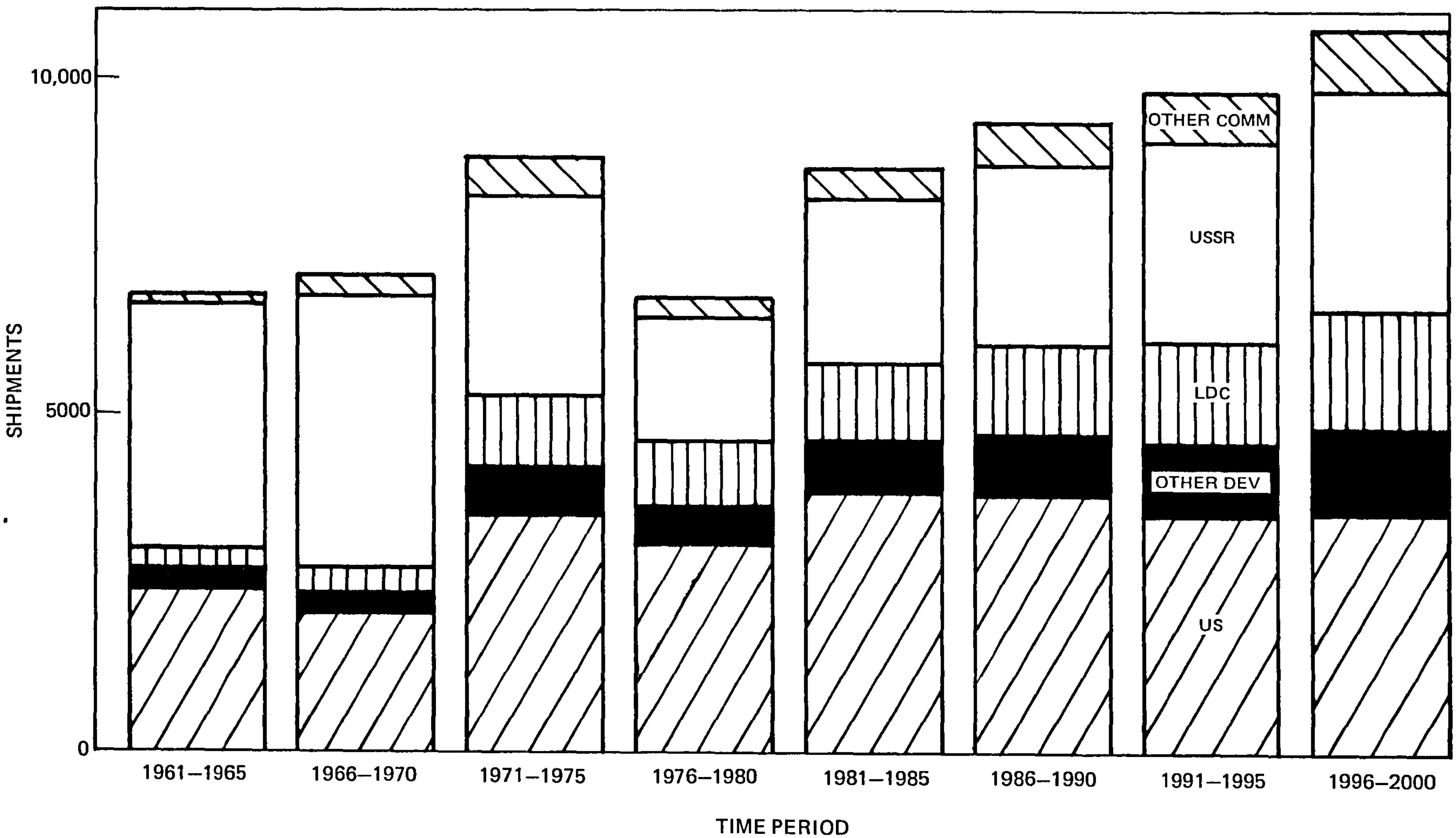


FIG 37

79–01–255–25

NOMINAL PROJECTION OF AG–AIR SHIPMENTS BY TYPE

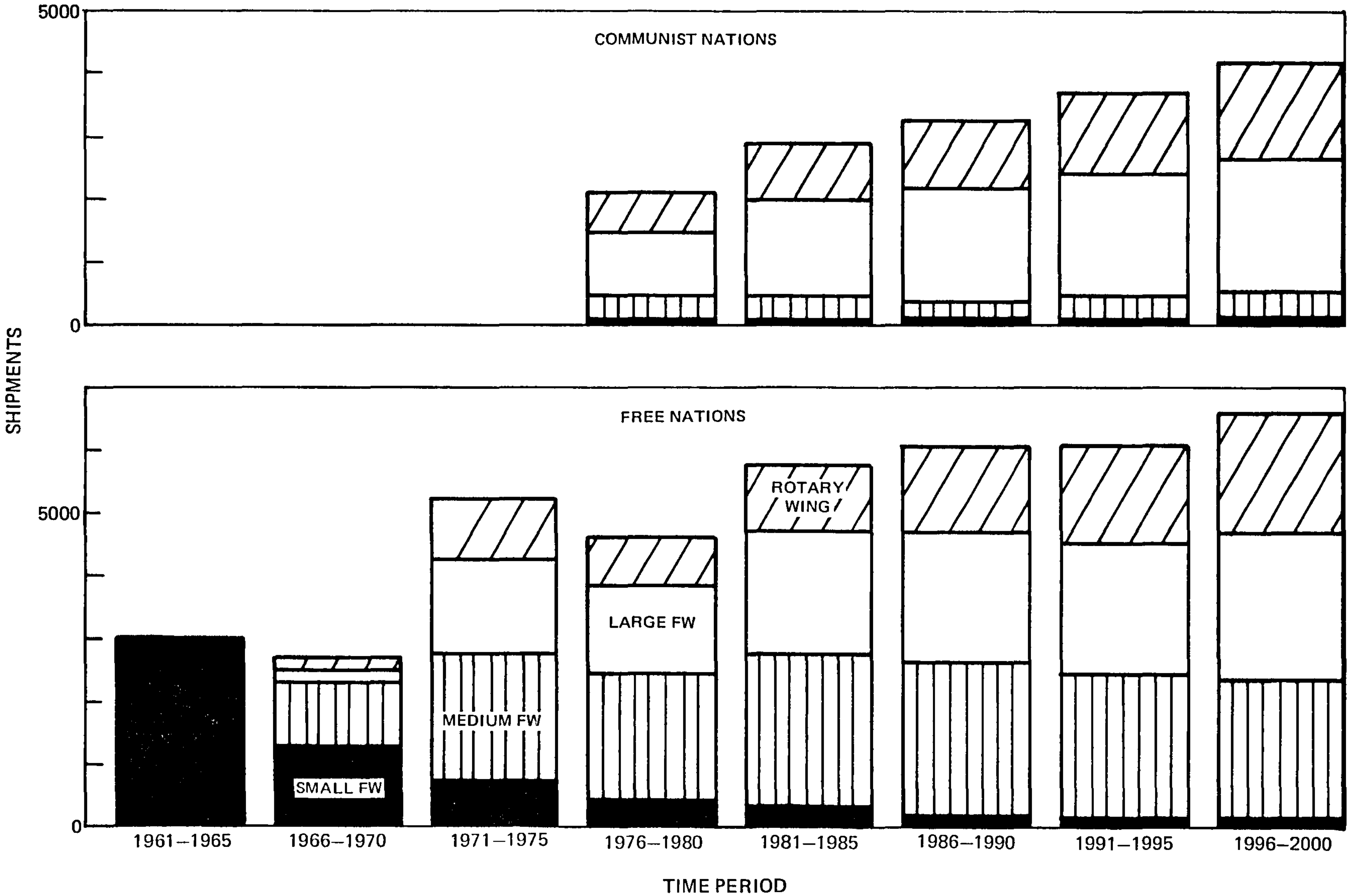


FIG. 38

79–01–255–14

Although the free-world figures are probably accurate, those for the communist nations may not be.

Shipments to US operators are predicted to remain relatively constant because of the increase in production and shift to larger aircraft. Shipments to other developed nations and LDCs will become an increasingly important factor compared to the historical period shown, but the domestic market will continue to be the major opportunity for US manufacturers. As shown in Fig. 38, manufacturers will find an expanding market for large fixed-wing and rotary-wing aircraft, a steady market for medium-size fixed-wing models, and a shrinking market for airplanes in the small fixed-wing category.

Effects of Revolutionary Changes in Ag-Air Industry

The nominal forecasts presented in the previous section are predicated on the assumption that evolutionary change will characterize the future of the ag-air industry, as has been the case in the past. However, the potential exists for a period of revolutionary structural changes in the industry. These revolutionary changes would not necessarily affect the forecast of treated area. That forecast was made by a method which accounted for increases in production, changing patterns of land holdngs in the major market regions and, indirectly, technological advances in both agricultural and aerial applications practice. Rather,these changes would primarily affect the types of aerial applications which will be emphasized in the future as compared to the historical period.

Two primary factors are expected to influence the future of the industry in this revolutionary scenario: 1) more stringent controls will be exercised on the use of chemical pesticides, herbicides, and other chemical agents, and 2) rising costs of agricultural products in a period of rapidly growing demand will stimulate increased attention to the benefits of aerially applied soil nutrients. In terms of ag-air volume (area treated) these two effects are in conflict and would tend to balance one another; i.e., a reduction in chemical applications for plant protection would decrease growth in the industry's primary area of operations, whereas increased penetration into aerial fertilization would present a new growth opportunity. That the two trends would cancel is a gross assumption which can only be justified on heuristic grounds. Moreover, it can be argued that the need to improve yields to meet rising demand will encourage further use of chemical agents, just as in the past. However, much attention is presently being given to nonchemical means of plant protection such as purely biological controls, and it is becoming increasingly apparent that some chemical agents have begun to lose effectiveness because of too-frequent or too-prolonged use. New agents will undoubtedly emerge to take their place, but the increased cost of developing and certifying agricultural chemicals has become a major deterrent which did not exist in the historical period. Therefore, slower growth in this segment of the market seems to be a realistic assumption. Rapid growth in aerial fertilization, on the other hand, can be argued on the basis of presently available data, as explained below.

Aerial Applications

In most of the world, aerial applications are focused on a relatively small variety of crops, and insecticides are the most common materials applied from the air. In the US, two crops, cotton and rice, account for almost half of the area treated by airplanes. Since pervasive insect infestations have been experienced on cotton crops, insecticide applications have long dominated US applications. The top half of Fig. 39 provides a history of US applications trends, as revealed by data from Ref. 9, showing the dominance of insecticide use. Although there has been a gradual trend toward increased aerial applications of fertilizers and herbicides, 50 percent of all aerially distributed materials are insecticides.*

The picture in the USSR, as indicated on the bottom half of Fig. 39, is quite different. Insecticides comprised only 27 percent of Soviet aerial applications in 1974, the most recent year for which data were available (Ref. 2), and the long-term trend has been sharply down. Applications of fertilizer** now account for more than 40 percent of aerial treatment area compared to only 11 percent in the US. The percentages of herbicide use are about the same in the two countries.

This disparity in applications practice can be partly explained by differing crop production. There is a greater emphasis on grains and roots in the USSR than in the US, less production of rice, sorghum, and soybeans, which are important ag-air crops in the US, and about equal production of vegetables and cotton. However, use of the scaling laws based on US practice resulted in almost exact prediction of aerial treatment in the USSR, suggesting that the disparity in Fig. 39 cannot be entirely explained by different crop mixes. Rather, it appears that there has been greater acceptance of ag-air as a means of spreading bulk materials such as fertilizers in the USSR than in the US. Whereas the US industry is still geared mainly to application of specialized chemicals, ag-air in the USSR has advanced more rapidly to the stage of applying routine materials from the air instead of by ground equipment. Important reasons for the wide use of aerial fertilizer in the USSR, according to Ref. 2, are: 1) vast fields inaccessible to ground equipment; 2) danger of damage to densely sown crops; 3) shortness of growing seasons relative to more temperate climates, and 4) need for accurate timing of applications to take advantage of rainfall in regions of marginal precipitation. Even helicopters are used for fertilization work on mountain hay fields and pastures, and on small fields.

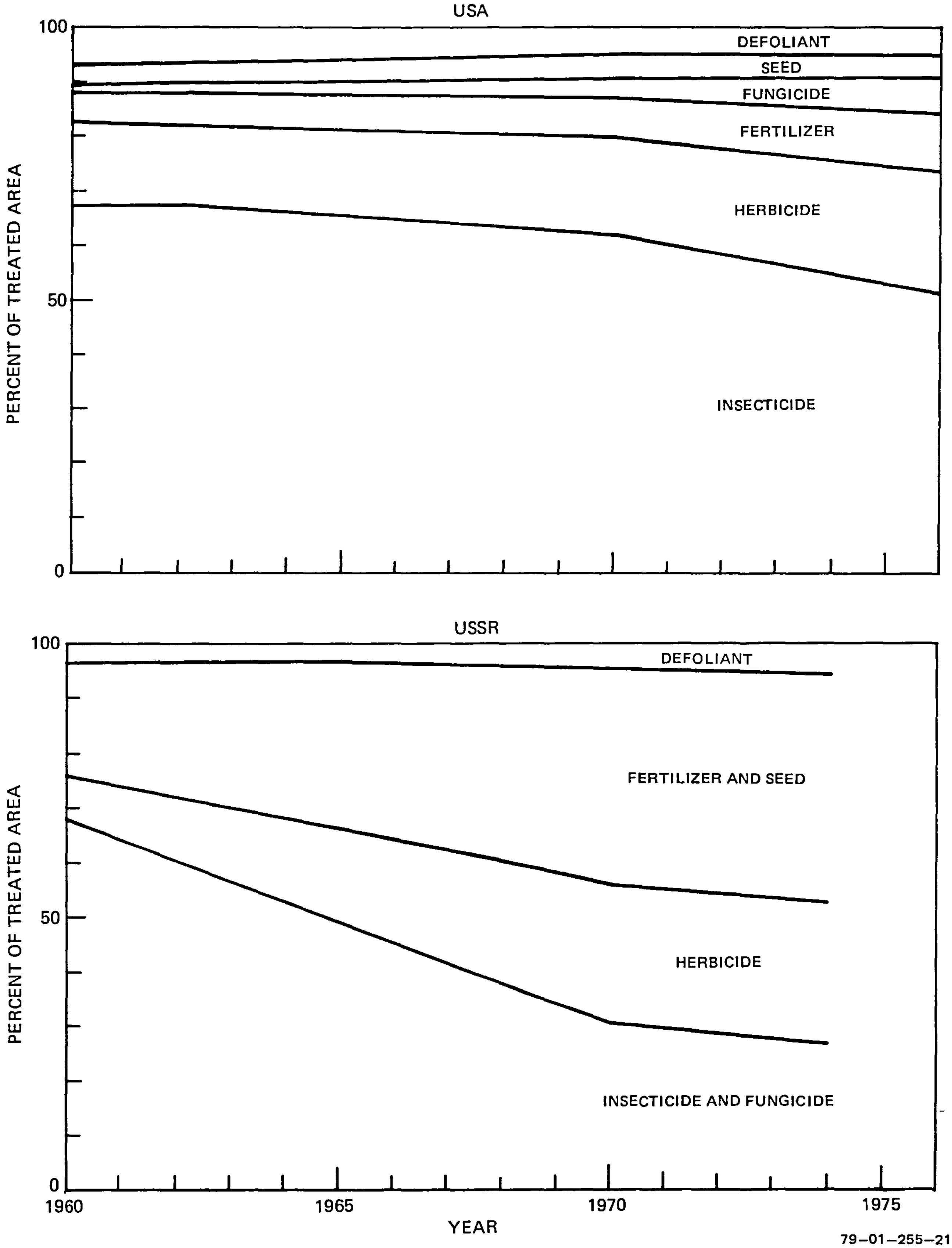
---

*Note that insecticide use has not declined but that other uses have grown more rapidly, thereby altering the percentage of treated area in each category of use.

**As used here, the fertilizer category also includes minerals added to improve soil fertility.

FIG 39

APPLICATIONS TRENDS IN THE USSR AND USA



79–01–255–21

There is sufficient information on US ag-air practice (e.g. Ref. 10) to estimate the percentage of treatment area for a particular crop which is dedicated to each type of application. Such a breakdown is provided under the columns headed US in Table 14 for each of the crop categories employed in this study. Using the US production figures for the last decade to estimate treated area for each crop, and US figures from Table 14 to allocate applications, the trends in the upper half of Fig. 39 were reproduced quite accurately. A similar exercise for the USSR did not reproduce the lower part of Fig. 39, even though the estimates of total treated area were good. Therefore, it is apparent that Soviet practice is not represented by the US allocations in Table 14.

Because the insecticide/fungicide category dominates for almost every crop, under US practice, only a shift of emphasis from that category to fertilizer and seed would reproduce the USSR experience. Furthermore, only signficant shifts for the most important Soviet ag-air crops would be effective, particularly grains and roots. Based on information in Ref. 2, and after some experimentation, it was found that the revised allocations in columns headed USSR in Table 14 made it possible to reproduce Soviet data.

The circumstances which prompted expansion of aerial fertilization in the USSR do not apply to all nations. However, it may be said that the same arguments may be advanced in support of aerial fertilization elsewhere. For example, while growing seasons are not short in the tropics, the need for multiple cropping results in a shortened period for each planting. Moreover, in the future, obtaining one additional crop per year to meet rising food demand could make aerial application of fertilizer as cost-effective in other parts of the world as it is in the USSR. It may also be argued that future expansion of agriculture into presently unused regions, such as the Llanos region of Colombia, will create accessibility problems similar to those common in the USSR and stimulate aerial application of bulk materials for the same reasons. Therefore, it is not unreasonable to assume that a model based on present Soviet practice is a possible model for the future of ag-air, just as current US practice is a good model for the present.

An allocation of aerial applications to describe the present world ag-air industry can be made by utilizing the appropriate columns of Table 14 to represent the USSR and the columns describing US practice to represent the rest of the world. A future allocation to go along with the nominal projections presented in the previous section can be calculated in the same way. The revolutionary scenario requires a revised table of allocations in which the various chemical-use categories are de-emphasized in favor of the fertilization and seeding categories. This allocation assumes that aerial seeding and fertilization will be expanded to 50 percent of all treated area by the year 2000 (as indicated by the USSR trend in Fig. 39) and that the percentages of chemical uses based on present US practice will decrease in equal proportions. The postulated applications for this scenario are provided in Table 14

TABLE 14

AERIAL APPLICATIONS PRACTICE
Percent of Treated Area

Crop Category	Insecticide and Fungicide			Herbicide, Defoliant & Dessicant			Fertilizer & Seed		
	US	USSR	Adv.	US	USSR	Adv.	US	USSR	Adv.
Wheat	27	3	13	60	40	17	13	57	75
Rice	6	2	4	25	30	16	69	68	80
Corn	66	50	49	28	28	21	6	22	30
Sorghum	71	60	55	26	31	20	3	9	25
Roots	75	10	25	15	25	5	10	65	70
Dry Beans	93	75	66	5	5	4	2	20	30
Soybeans	60	42	44	36	36	26	4	22	30
Grains	27	3	9	60	40	21	13	57	70
Nuts	92	92	88	8	8	7	0	0	5
Sugar Cane	85	85	81	15	15	14	0	0	5
Sugar Beets	85	70	67	10	10	8	5	20	25
Cotton	80	50	58	19	25	14	1	25	28
Vegetables	97	47	49	3	3	1	0	50	50
Fruit	100	90	90	0	0	0	0	10	10
Citrus	100	100	100	0	0	0	0	0	0
Tobacco	84	74	76	15	15	14	1	10	10
Timber	94	89	85	0	0	0	6	11	15
Rangelend	10	5	9	88	88	81	2	7	10
Area Insects	100	100	0	0	0	0	0	0	0

under the columns labeled "Advanced" practice. These figures were used to describe all regions except the USSR, for which the "USSR" columns were assumed to apply for the year 2000.

A bar chart summarizing present and future applications patterns under the nominal and advanced scenarios is provided in Fig. 40. The results are presented for both the free world, which excludes the USSR and other communist nations, and for the entire world. In every case, it can be seen that the insecticide/fungicide category decreases as a percentage of total treated area between 1975 and 2000. But, whereas the decrease is modest if present (i.e. US) applications practice is assumed for 2000, a very significant drop occurs with advanced practice. Furthermore, although fertilization and seeding increase in each case, only the advanced scenario produces a significant change in this category. The herbicide/defoliant/ dessicant category is seen to be almost unaffected with a continuation of present practice, and to suffer a significant decrease in the advanced-scenario case.

Despite the fact that large percentage reductions in chemical agent applications occur in Fig. 40, it is important to understand that these reductions are only in the percentages of area treated and not in their absolute values relative to 1975. To illustrate, the tabulation below describes what is happening in each case.

FREE WORLD

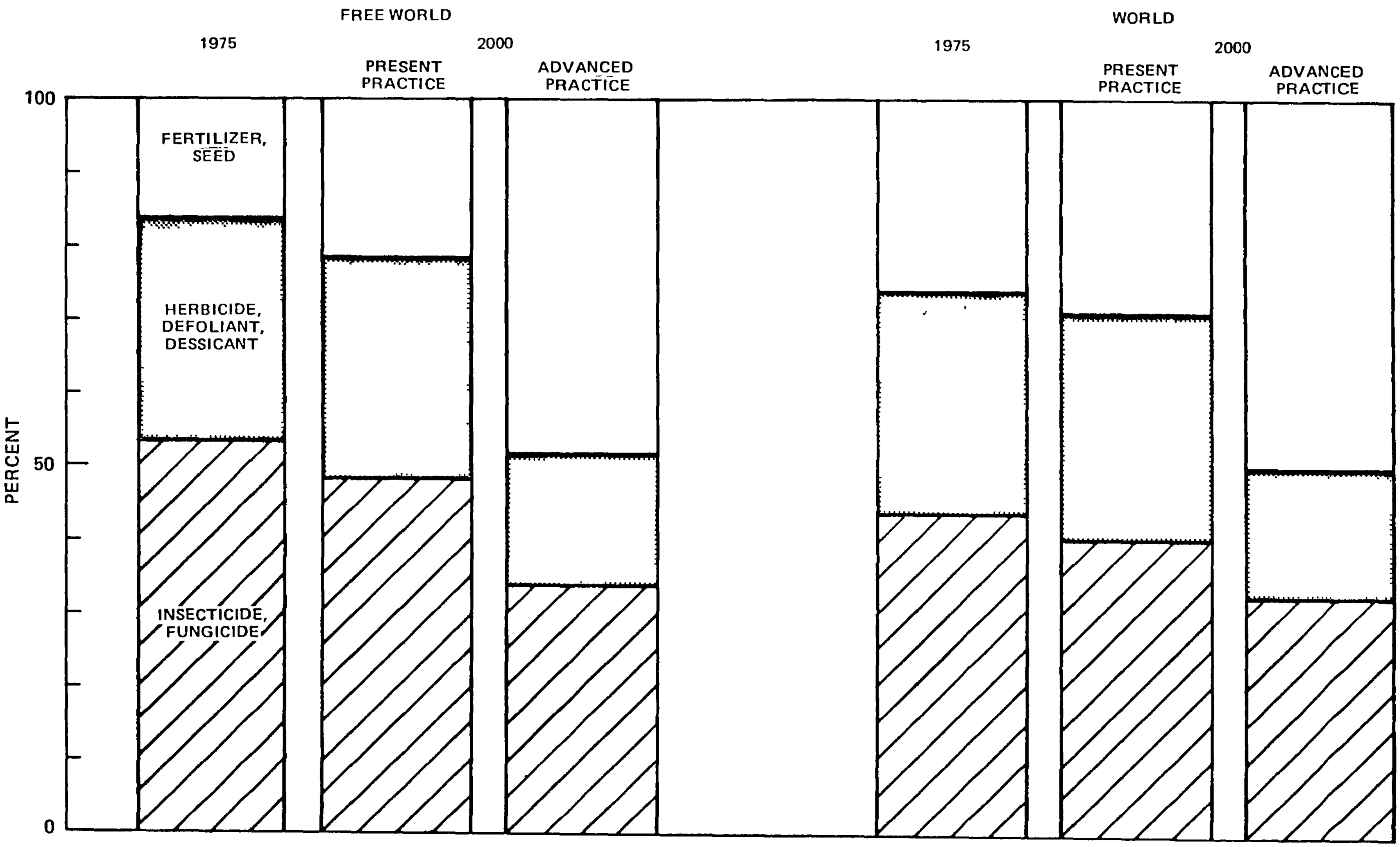
	Treated Area, 10^6 ha		
	1975	2000	
Application		Present Practice	Advanced Practice
Insect./Fung.	69.8	205.7	144.7
Herb./Def./Dess.	39.9	128.4	76.4
Fert./Seed	21.5	92.2	205.2
Total	131.2	426.3	426.3

ENTIRE WORLD

	Treated Area, 10^6 ha		
	1975	2000	
Application		Present Practice	Advanced Practice
Insect./Fung.	102.3	285.6	230.4
Herb./Def./Dess.	69.3	216.3	122.6
Fert./Seed	60.3	202.8	351.7
Total	231.9	704.7	704.7

These data show clearly that due to the large projected increases in treated area, growth occurs in each applications category for every case.

TREATED AREA BREAKDOWN BY AERIAL APPLICATIONS SCENARIO



79-01-255-19

FIG 40

AGRICULTURAL AIRCRAFT REQUIREMENTS

The technical and economic characteristics of present ag-airplanes were summarized earlier in Tables 1 and 2. The basis for estimating the operating costs of the airplanes in those tables were the cost equations given in Table 3. The analysis which will be described in this section involves an evaluation of the relative performance of agricultural aircraft in various operational tasks. Comparisons of several aircraft were made, based on a parametric analysis of variables such as application rate, loading rate, swath width, and field size. Five generalized cases of applications were considered: ultra-low volume (ULV), insecticides, herbicides, and two application rates of fertilizers. These applications represent cases of very low, low, medium, high, and very high volume, respectively. In order to represent a full range of future technology choices, five aircraft types were analyzed, ranging from an existing small aircraft to a design of a future large airplane. The choice of airplanes, and their characteristics, were arrived at after consultation with the NASA.

Analysis of Aircraft Costs

To evaluate the relative productivities and costs of existing and future aircraft, a simple operational model was used, based on that presented by Akesson and Yates (Ref. 1). The productivity of an aircraft can be expressed by the following equation:

$$P = \frac{Q_L/Q_A}{(T_R/60) + (D_F/V_F) + (K \cdot Q_L/Q_A \cdot S_W) \cdot (1/V_S + T_T/60 \cdot D)} \qquad (1)$$

where

P = productivity [ha/hr, acres/hr]

Q_L = aircraft load [kg, lb]

Q_A = application rate [kg/ha, lb/acre]

T_R = load time x number of loads [min]

T_T = turn time [min]

D_F = ferry distance per load x number of loads [km, mi]

D = field length [km, mi]

S_W = swath width [m, ft]

V_F = ferry speed [km/hr, mph]

V_S = field speed [km/hr, mph]

K = 10 for metric units
8.25 for US units

It should be noted that the equation, as given in Akesson and Yates, was lacking the "Q_A" term in the numerator. Also, the ferry distance has been given a clearer interpretation. Since the expression is based on the productivity per load, the ferry distance is defined here as the average round trip distance from the loading point ("wheels off") to the beginning of each swath ("spray on") for each successive hopper loading. If the loading point is at the edge of the field, the average ferry distance is simply one-half the length of the field. If the airplane is loaded further away, this additional distance must be added each time the airplane is reloaded. The first and last ferries from the home base to the field were ignored, since that distance is typically small relative to the other parameters. Each time the airplane is loaded, an additional ferry must be made and the corresponding term in the equation increased. Also, the loading time per hopper is multiplied by the number of loads it takes to spray the field. These parameters depend on the field size and application rate, and are computed externally before being entered into the productivity equation, as follows:

$$N_L = \text{No. of loads} = \frac{\text{Field size [ha]} \times Q_A}{Q_L}$$

$$T_R = \text{Loading time} = N_L \times \text{Load time per hopper}$$

$$D_F = \text{Ferry Distance} = \left\{ \begin{array}{ll} N_L & \text{if integral} \\ |N_L| + 1 & \text{if non-integral} \end{array} \right\} \times \text{Round trip ferry distance}$$

For the operational analysis, five aircraft types were chosen for comparative purposes:

1. Piper Pawnee
2. Cessna AgWagon
3. "Improved" AgWagon
4. Ayres Turbo Thrush
5. Lockheed AGB-7-TB1 design (Ref. 32)

These airplanes are meant to represent a wide technology range which encompasses both existing and hypothetical future models. The characteristics of these airplanes are given in Table 15. The Pawnee and AgWagon are representative of existing small- and medium-sized aircraft, respectively. The "improved" version of the AgWagon assumes hypothetical improvements in

TABLE 15

REPRESENTATIVE AG-AIRCRAFT CHARACTERISTICS

	Pawnee	AgWagon	Improved AgWagon	Turbo Thrush	AGB-7-TB1
Acquisition Cost, $	38,220	43,950	50,000	187,000	464,000
Life, yrs	10	10	10	10	10
Fuel Consumption, gal/hr (liters/hr)	13 (51)	15 (57)	12 (46)	34 (129)	124 (471)
Hopper Capacity, gal (liters)	150 (570)	200 (760)	280 (1064)	500 (1900)	1570 (5966)
Swath Width, ft (m) Liquid/Dry	55/35 (17/11)	60/40 (18/12)	65/50 (20/15)	65/55 (20/17)	70/70 (21/21)
Max. Power, kW	175	224	312	559	1134
Fuel Type	Av. Gas	Av. Gas	Av. Gas	Diesel	Diesel
Ferry Speed, mi/hr (km/hr)	115 (185)	140 (224)	150 (240)	160 (256)	170 (272)
Spray Speed, mi/hr (km/hr)	90 (140)	120 (192)	130 (208)	140 (224)	160 (256)
Turn Time, sec	20	30	25	20	25
Loading Rate, lb/sec (kg/sec) Manual/Advanced	50/100 (23/45)	50/100 (23/45)	50/100 (23/45)	50/100 (23/45)	50/100 (23/45)

performance and hopper capacity, accompanied by increases in acquisition cost and operating cost. The Turbo Thrush is an existing turbine-powered aircraft of a larger size. Finally, a very large airplane designed by Lockheed (Ref. 32) was incorporated in order to allow for potential future growth in very high-volume applications.

The airplane data of Table 15 were then used to calculate operating costs, as summarized in Table 16. Since the operating cost includes interest, hangar and airstrip, and crew costs, the hourly cost is somewhat higher than given by Lockheed for their advanced design. Although the operating cost calculation is only an approximation, it is a valid approach for making comparisons among the airplanes. The 600 hrs/yr utilization represents an operating environment of the future, which features improved technology and operating practices, as explained earlier.

For the analysis, these airplanes were compared using the parameters shown in Table 17. Two scenarios were chosen for each airplane. The "base" airplane assumes a manual system of loading and a ferry speed equal to the field speed. The "advanced" operating environment postulates an automated system for rapid loading, and improvements in operations such as higher ferry speed, less dead time, better monitoring of payload, improved take-off and landing procedures, and closer runways. These improvements are reflected by the faster effective ferry speed.

Finally, the airplane comparison was made on the basis of cost per hectare as a function of field size. As would be expected, actual and relative costs depend strongly on application rate and field size. Calculations were made for five typical application rates of materials, as follows:

1. ULV - 4 kg/ha
2. Insecticides - 15 kg/ha
3. Herbicides - 75 kg/ha
4. Fertilizers/Seeding - 200 kg/ha
5. Fertilizers - 300 kg/ha

Field sizes up to 250 ha were included in the parametric study. Such fields would include the majority of farms, as indicated by data in Ref. 25. For larger areas, the cost curves can easily be extrapolated, as will be seen.

The results for the "base" airplanes are shown in Figs. 41 to 44 for typical insecticide, herbicide, and fertilizer applications, respectively. At very low application rates, such as for insecticides (15 kg/ha), costs decrease with increasing field size, because turn time becomes a significant proportion of the time in spraying small fields. The model thus accounts for the undesirability of spraying very small fields by air. The Pawnee and Improved AgWagon are the lowest-cost airplanes in this comparison. The

TABLE 16

OPERATING COST ESTIMATES

	Pawnee	AgWagon	Improved AgWagon	Turbo Thrush	AGB-7-TB1
Total Fixed, \$/yr	11,580	13,310	14,630	48,410	117,405
Depreciation	3,785	4,395	5,000	18,700	46,400
Interest	2,100	2,415	2,750	10,285	25,520
Taxes & License	1,260	1,450	1,650	6,090	15,310
Hangar & Airstrip	630	725	850	3,045	7,655
Insurance	3,805	4,145	4,420	10,290	22,520
Total Variable, \$/hr	43.0	47.9	57.0	72.9	127.3
Fuel & Oil	8.5	10.8	15.0	23.3	47.2
Maintenance & Overhaul	16.5	19.1	24.0	31.6	62.1
Crew	18	18	18	18	18
Total Operating Cost, \$/hr					
Utilization: 400 hr/yr	72.0	80.7	93.6	193.9	421.0
600 hr/yr	62.3	69.8	81.4	153.6	323.0

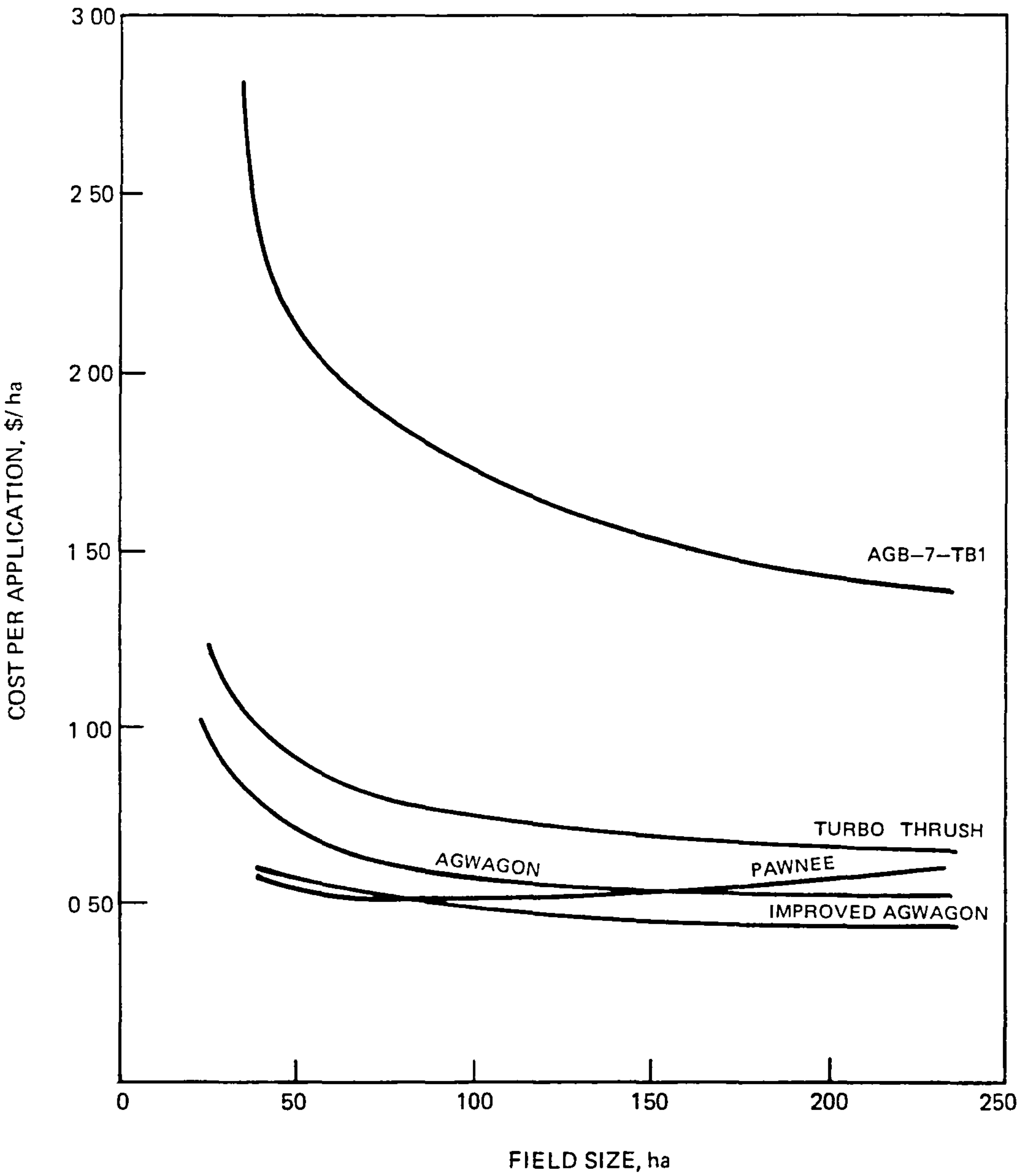
TABLE 17

MODEL PARAMETERS

	Pawnee	AgWagon	Improved AgWagon	Turbo Thrush	Lockheed AGB-7-TB1
A/C Load (Q_L), kg	500	750	1050	1900	5950
Loading Time, min., Man.	0.4	0.6	0.8	1.4	4.4
Adv.	0.2	0.3	0.4	0.7	2.2
Turn Time (T_T), min.	0.3	0.5	0.4	0.3	0.4
Nominal Swath Width (S_W), m	17	18	20	20	21
Field Speed (V_S), km/hr	140	190	210	225	260
Ferry Speed (V_F), km/hr,	140	190	210	225	260
Adv.	185	224	240	256	272
Operating Cost, $/hr:					
Utilization. 400 hr/yr	72.0	80.7	93.6	193.9	421.0
600 hr/yr	62.3	69.8	81.4	153.6	323.0

INSECTICIDE

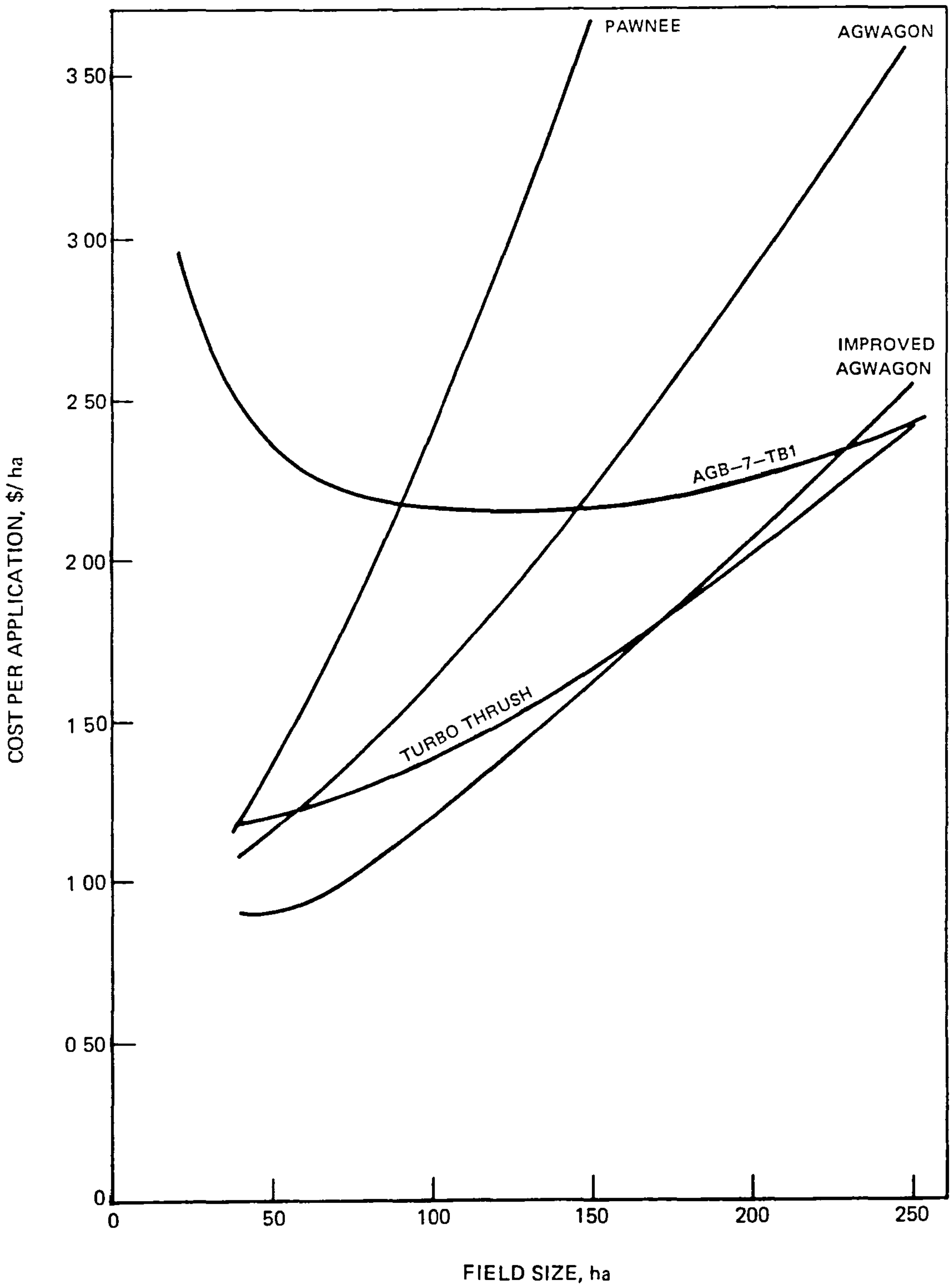
15 kg/ha



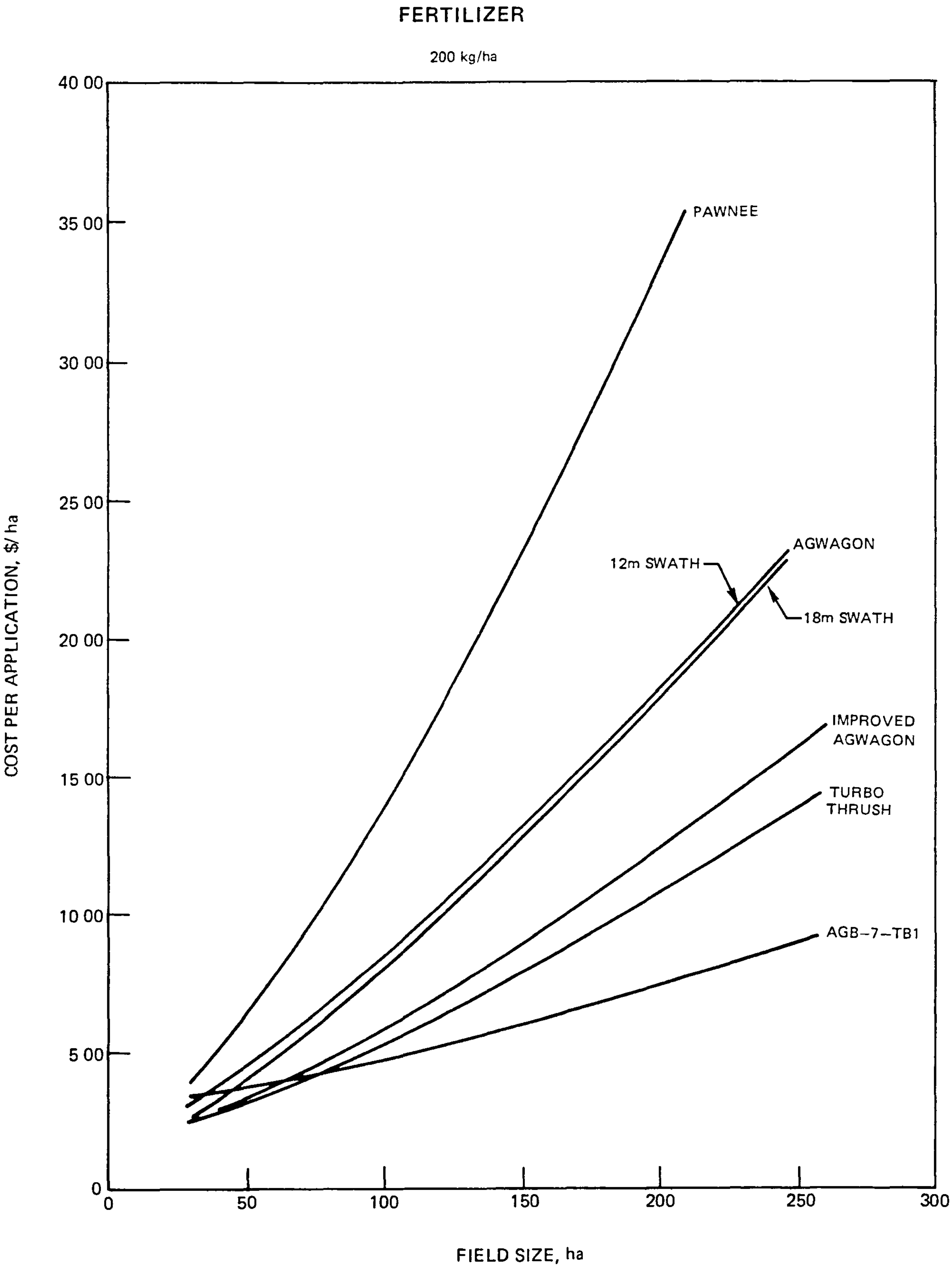
79–01–255–36

HERBICIDE

75 kg/ha

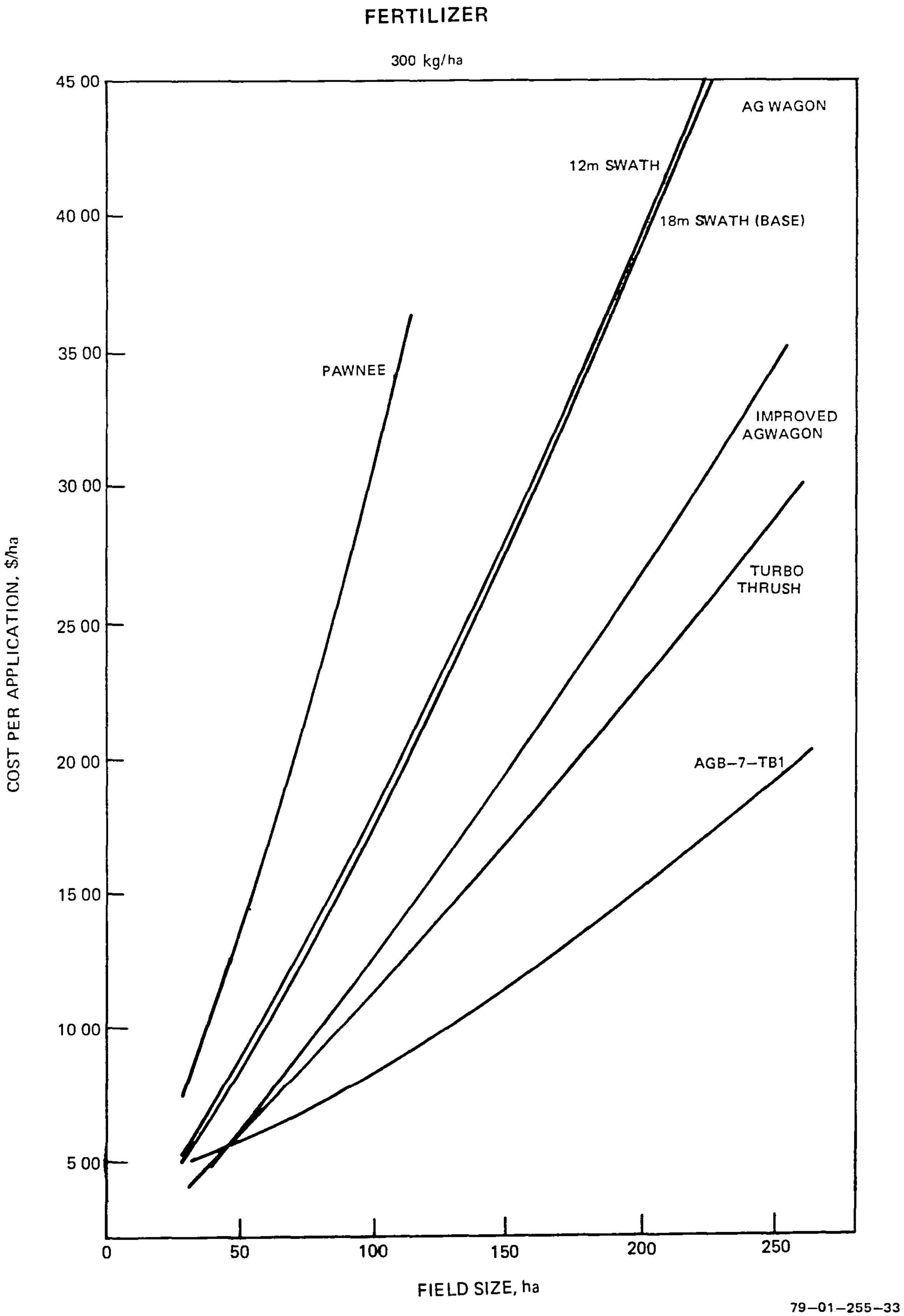


79–01–255–37


FERTILIZER
200 kg/ha
40 00
35 00
30 00
25 00
20 00
15 00
10 00
5 00
0
COST PER APPLICATION, $/ha
0
50
100
150
200
250
300
FIELD SIZE, ha
PAWNEE
AGWAGON
12m SWATH
18m SWATH
IMPROVED AGWAGON
TURBO THRUSH
AGB-7-TB1

79-01-255-32

FIG 44


FERTILIZER
300 kg/ha
AG WAGON
12m SWATH
18m SWATH (BASE)
PAWNEE
IMPROVED
AGWAGON
TURBO
THRUSH
AGB-7-TB1
COST PER APPLICATION, $/ha
45 00
40 00
35 00
30 00
25 00
20 00
15 00
10 00
5 00
0
50
100
150
200
250
FIELD SIZE, ha
79-01-255-33

large Lockheed airplane is significantly higher in cost since the hopper is only partly full for fields under about 400 ha. Similar curves were obtained for ULV application, with only a slight decrease in cost. Unlike insecticide work, the Pawnee was seen to have a downward sloping curve in the entire range of field sizes.

The trends are somewhat different with herbicides (75 kg/ha). For the smaller airplanes, costs decrease up to about 50 ha, but then increase rapidly because of increased ferrying required to apply the larger quantities of material to larger fields. Therefore, there is an optimum field size for each airplane, although only the largest airplane reaches its minimum within the field size range of interest. The AgWagon becomes most expensive for fields above about 150 ha, while the relatively flat cost curve of the AGB-7-TB1 makes it the best choice above 250 ha. The Improved AgWagon and Turbo Thrush are the lowest-cost airplanes over most of the field-size range.

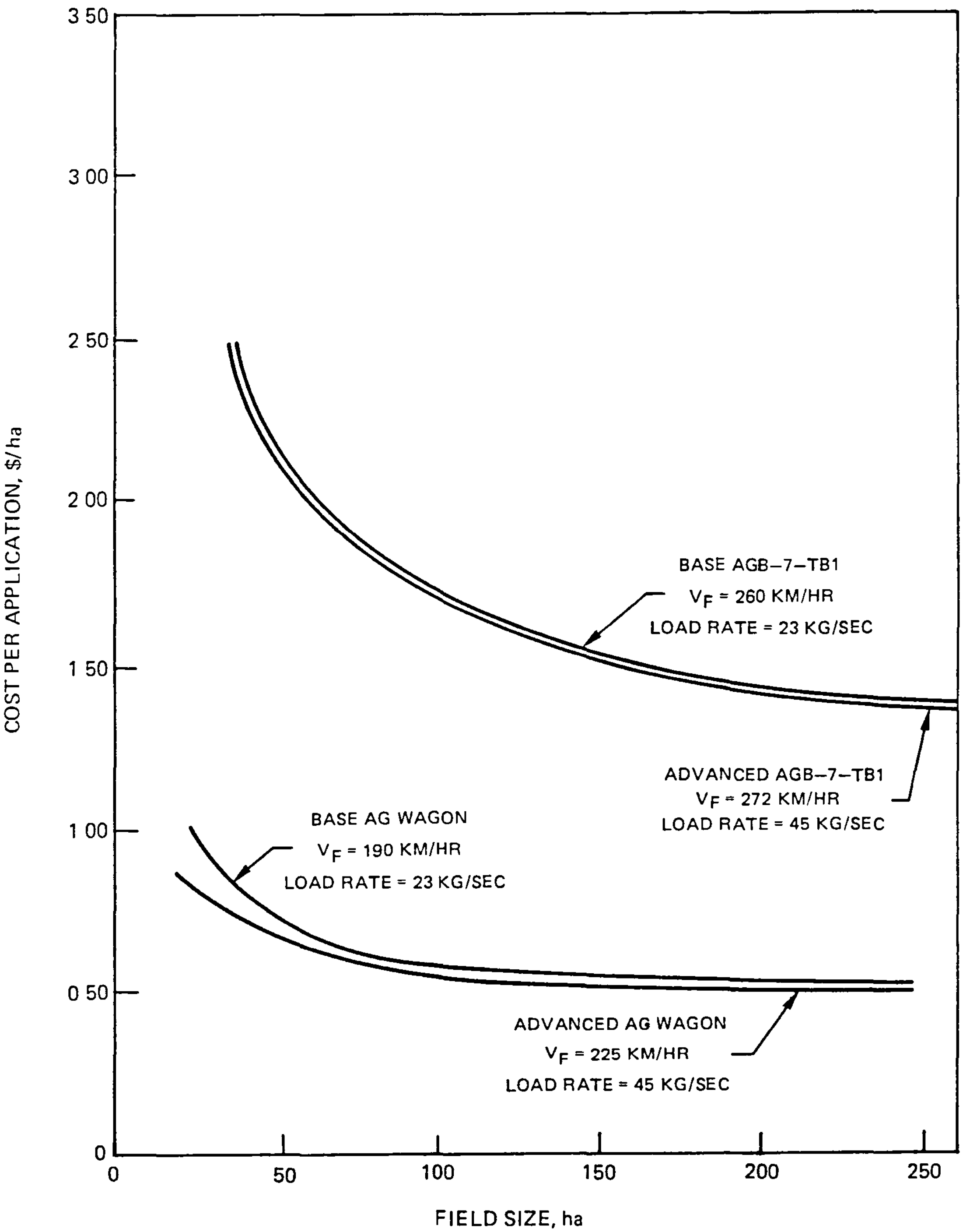
At application rates characteristic of fertilizers (200 and 300 kg/ha), costs increase rapidly as field size increases, and ferry distance becomes increasingly important. As seen in Figs. 43 and 44, airplanes with large payloads become attractive for servicing larger fields because they reduce the number of ferries. Swath width is much less critical in fertilizer application, as seen for the AgWagon. Even if the swath width for application of dry material is reduced to 12 m, the effect on cost is minimal. For higher application rates, therefore, it is more important to reduce loading and ferrying time than to increase swath width, although the importance of swath width would increase with increasing payload.

The next set of curves (Figs. 45 to 48) shows a sensitivity analysis of reducing loading and ferrying time for two airplanes, the AgWagon and the AGB-7-TB1. Improvements in these parameters were indicated in Table 17. In the figures, these airplanes are labeled as "advanced" versions of the two airplanes analyzed previously. From these figures, it can be seen that the improvements become very significant for large fields and high application rates, producing up to a 40 percent reduction in cost in the best case. At low application rates the effect is negligible.

The preceding analysis has shown that for small application rates, the absolute differences among airplanes on a unit cost ($/ha) basis are small (of the order of $1/ha), even though the relative differences may be large. On the other hand, the cost variation at high application rates is very large (on the order of $10/ha). Furthermore, there is great sensitivity to improvements in operations (ferrying and loading time) and the technology of airplanes (payload) for the high application rates. Therefore, it may be possible that fertilization by air could be economically competitive with surface machines, since the magnitude of potential cost reductions is quite large. In the next section, these improvements are examined with respect to other costs, such as material and surface application costs.

INSECTICIDE

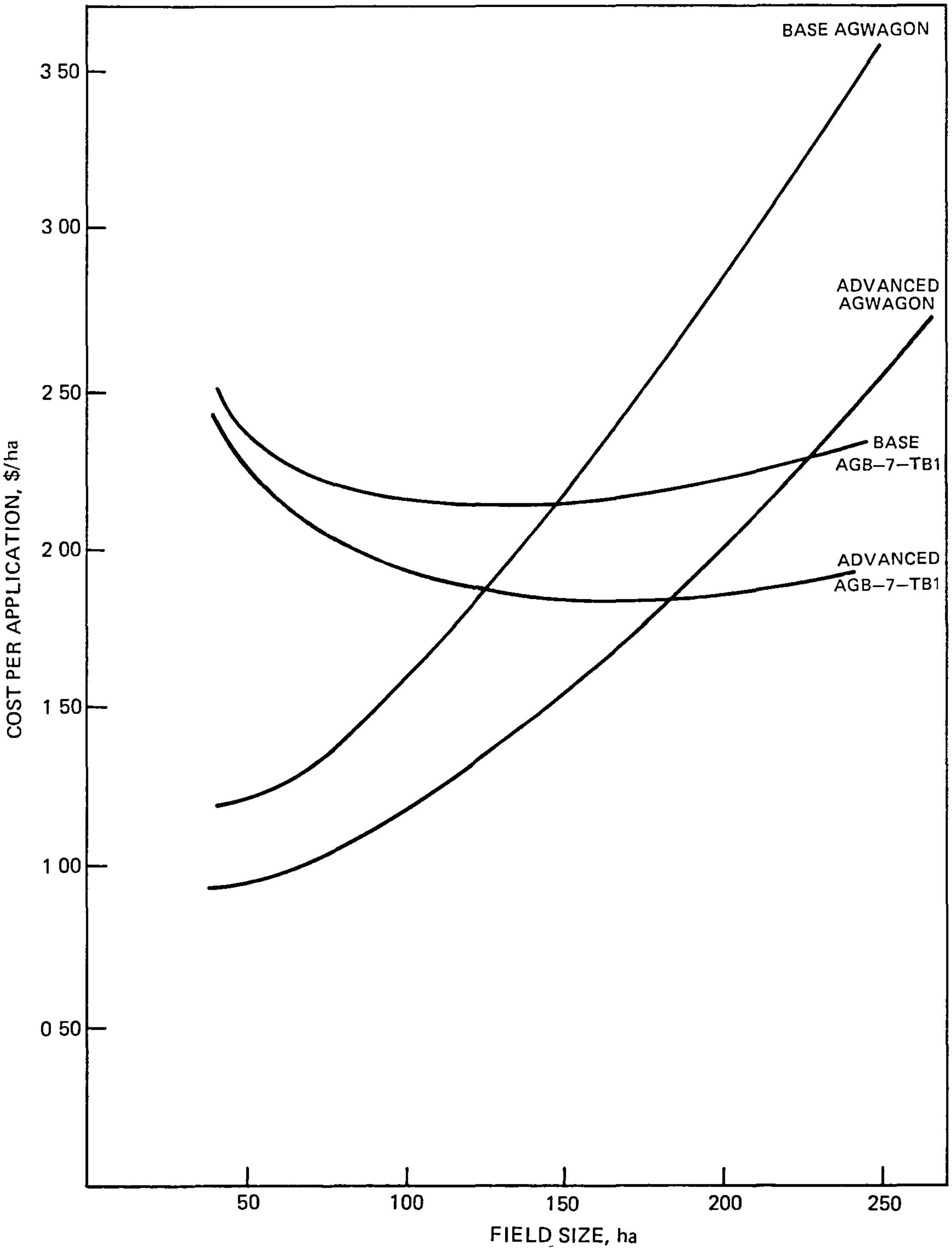
15 kg/ha



79–01–255–35

HERBICIDE

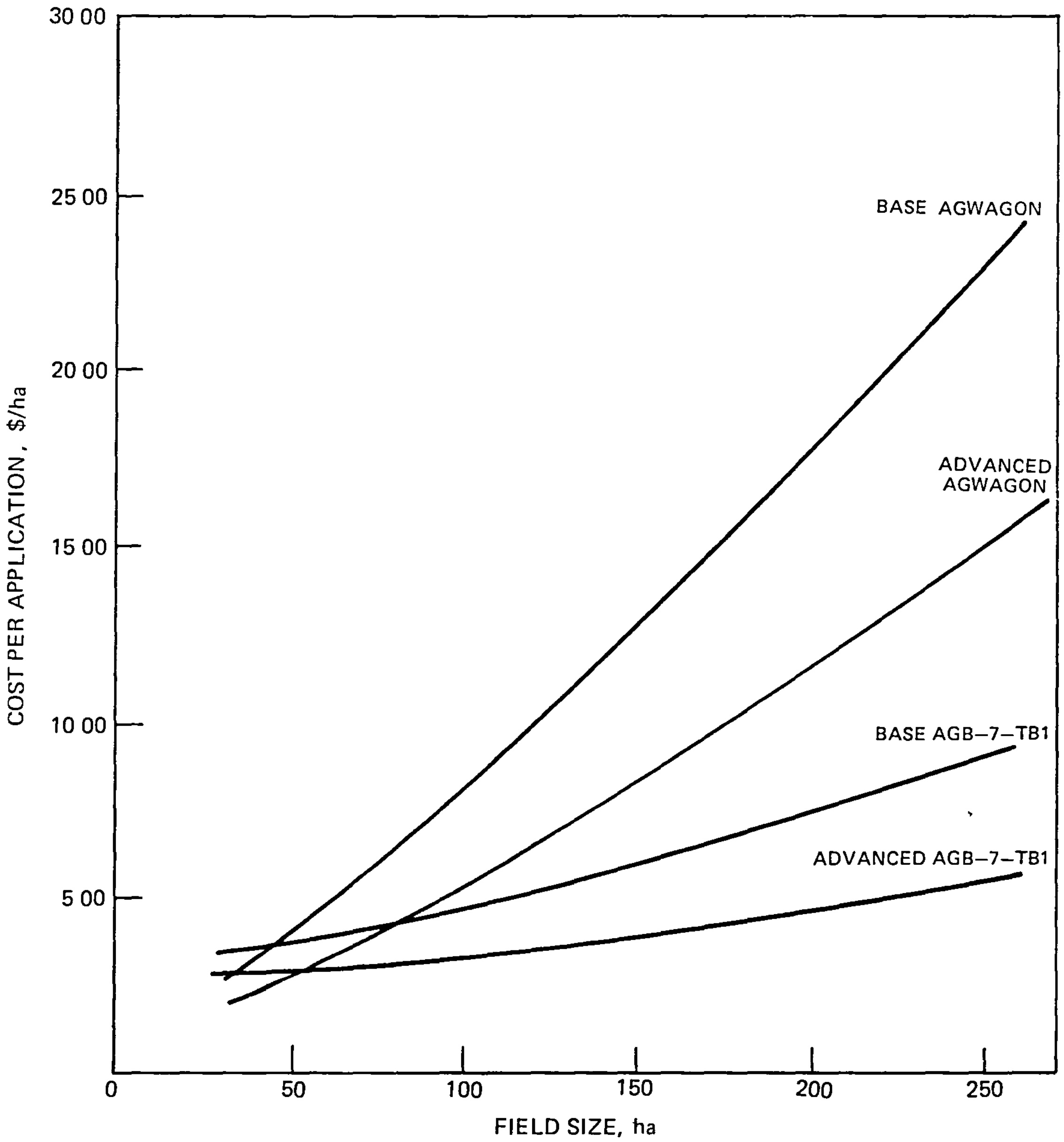
75 kg /ha



79–01–255–26

FERTILIZER

200 kg/ha

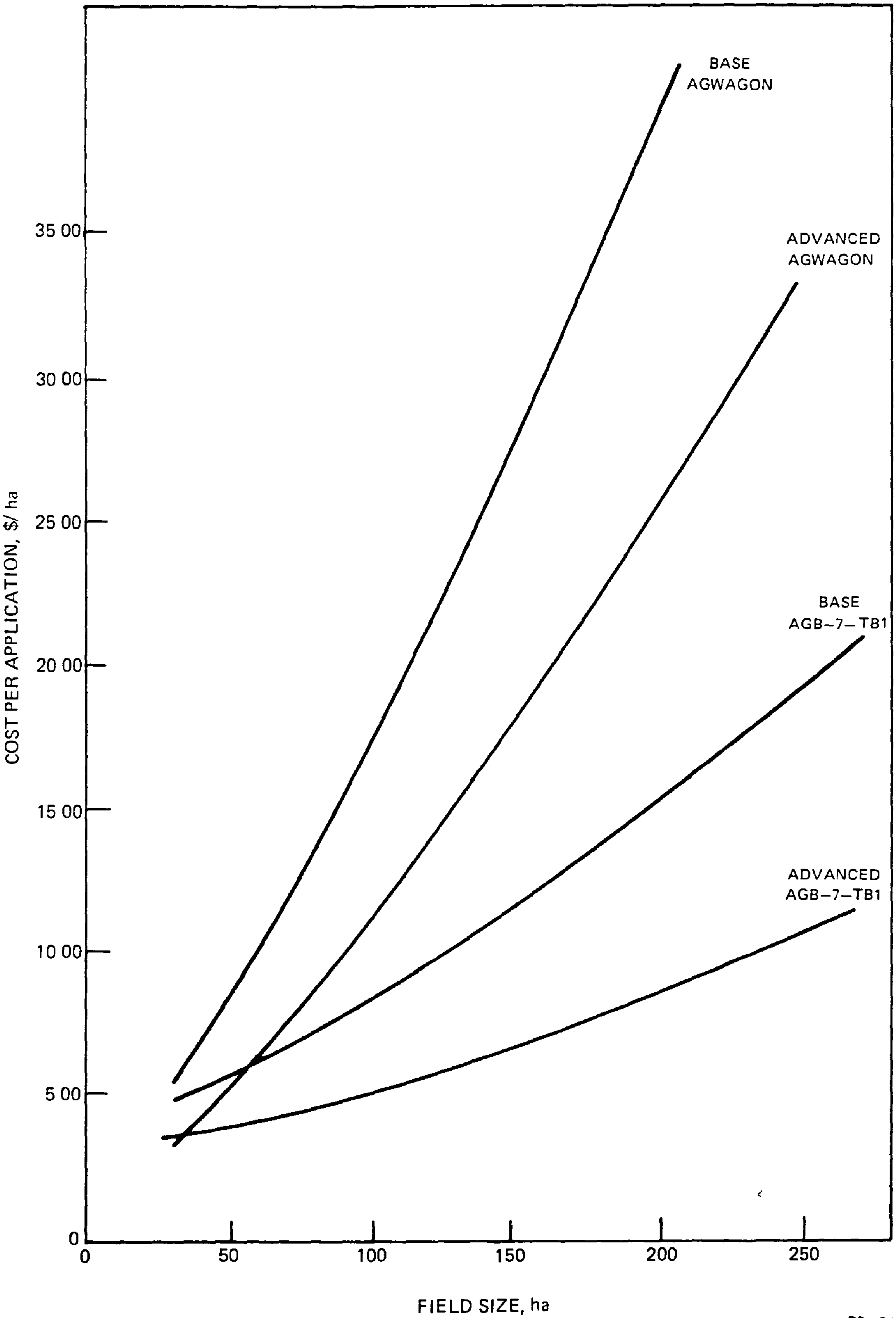


79–01–255–24

FIG 48

FERTILIZER

300 kg/ha



79-01-255-38

Factors Affecting Future Aircraft Choices

Before any conclusions can be drawn about the significance of reduced airplane operating costs, these costs must be related to other costs incurred by the operator and/or farmer. The primary cost is that of the materials themselves, although these costs are difficult to generalize because they vary among crops and regions, as well as from manufacturer to manufacturer and method of application (Ref. 10). Even though it is possible to give only broad ranges of materials costs, some insight can still be gained into the relative cost of applications vs materials. As seen in Table 18, material cost is very large compared to minimum application cost (advanced technology) for insecticide spraying, and is even larger for ULV applications. As application rates increase (herbicides and fertilizer), material costs become less dominant. The ratio of materials cost to application cost in Table 18 decreases to a value of about 3:1 for the highest application rate and largest field. The ratio is close to unity if the current technology application cost ($50) is used. The implication is that there is a greater need for improvements in aerial application technology and operations at higher application rates than for the low-volume work, which currently dominates in the ag-air industry.

Because chemical costs are much higher than the costs of application, efforts should be directed not just at reducing aircraft operating cost, but at improving the efficiency of spraying. If the airplane distribution system could be improved such that the same biological effectiveness were achieved using less material, considerable savings in total cost would be achieved. For example, just a 5 percent saving in the quantity of insecticide applied is approximately one-half the airplane-related cost of a typical aerial application. The savings are less dramatic at the higher application rates, as seen in Table 18, suggesting that, from an economic standpoint, research effort in insecticide spraying (and other low-volume, high-value applications) should be made in the area of better distribution rather than in reducing airplane operating cost _per se_. From an overall perspective, there ought to be a trade-off between the higher cost of an improved technology and the attendant saving in material cost.

An important practical consideration in assessing the impact of a cost reduction are the roles of the applicator and the grower. If the applicator provides the chemicals as a part of his service, he will seek to minimize the sum of application and materials costs. Under these conditions, the applicator would be sensitive to improvements in distribution and would be likely to adopt them if they reduce his cost and make him more competitive. On the other hand, less motivation for improving the efficiency of distribution exists if the farmer provides the chemicals for the applicator (as in Colombia). The applicator then seeks to minimize only his own operating cost by choosing a lower-cost technology and/or applying less efficiently (e.g., larger swaths). In this respect, it seems more desirable that a "package" service be provided, assuming adequate control by the agronomist and farmer is maintained.

TABLE 18

COST OF AERIAL APPLICATION VS MATERIALS
(cost per hectare for one application)

Field Size	Range of Application Cost/Ha		Typical Range of Material Costs/Ha	Ratio of Material Cost/Min. App. Cost
		INSECTICIDES		
40 ha	$0.60 - $2.50		$5 - $10	8 - 17
140 ha	0.45 - 1.60		5 - 10	11 - 22
240 ha	0.45 - 1.30		5 - 10	11 - 22
		HERBICIDES		
40 ha	$0.90 - $2.50		$5 - $20	6 - 22
140 ha	1.50 - 2.20*		5 - 20	3 - 13
240 ha	2.30 - 3.50*		5 - 20	2 - 9
		FERTILIZERS (low application rate)		
40 ha	$3.00 - $ 3.50*		~ $35	12
140 ha	5.50 - 12.00*		35	6
240 ha	8.50 - 22.00*		35	4
		FERTILIZERS (high application rate)		
40 ha	$ 5.00 - $ 7.00*		~ $50	10
140 ha	11.00 - 26.00*		50	5
240 ha	18.50 - 49.00*		50	3

* Not including Pawnee

Another important factor affecting airplane costs is utilization. The comparison of airplanes has assumed 600 hrs annual utilization for each airplane. It may not be possible to utilize a large aircraft as effectively as a smaller one, particularly if it is used only for limited purposes such as fertilizer application. The seasonal peaking in certain applications (e.g., fertilizer, which is applied mostly at the beginning of a season) would also reduce the annual utilization. Because a large advanced aircraft is not economic for low-volume work, a good market must be assured to maintain utilization equal to that of other airplanes. For this reason, the best airplane size may be predicated on multiple aerial application missions (at various application rates), rather than on one high-rate mission.

Comparison with Surface Equipment

Although the decision to use either surface or aerial technology is rarely made for strictly economic reasons, extensive penetration of the fertilizer application market by air will require justification on economic grounds. Unlike pesticide applications, most fertilization is done prior to emergence of any growth. It should be noted that the pre-emergence fertilization practice places more fertilizer in the soil than the plant can utilize, resulting in losses in the air and through leaching. For this reason, pre-emergence fertilization is a controversial practice. Aerial application of nutrients offers the capability of proper timing in the application of fertilizers, so that they are used in only the required quantities and at the most beneficial points in plant life cycles. Information on the cost of surface application is sparse, since it is so dependent on the wide range of available machinery (Ref. 23), the terrain, materials applied, and the method of cost accounting (Refs.34 and 35). Furthermore, none of these sources explicitly considers the field size or loading operations other than through the effective speed of the machine.

Rather than analyze a wide range of tractor/spreader combinations, one particular machine was chosen to represent a modern, specialized piece of equipment. This is the John Deere 6000 Hi-Cycle Sprayer, a diesel-powered, high-clearance sprayer with a 320-US gallon tank and a 47-ft boom (Ref. 36). Because of its clearance, it can be used to spray tall or bushy crops in later stages of maturity. Although designed for low-volume insecticide work, operating cost for other applications is not expected to be significantly different (Ref. 35). Using the parameters and equations given in Ref. 34, operating costs were calculated assuming a ten-year equipment lifetime and an economic life of 2000 hrs. This converts to an annual utilization of only 200 hrs, as verified in the literature (Ref. 34). The cost of application (machine and operator) was estimated to be about $2.50/acre, or about $6/ha, which was confirmed by correspondence with John Deere*.

*Correspondence with John Deere Des Moines Works, August 22, 1978.

In comparison with aerial application costs in Table 18, ground application costs are higher for insecticides and herbicides, but not for fertilizers, in general. It should be stressed that this is a very crude comparison. Typical spraying equipment for pesticides is probably not as sophisticated and expensive to operate as the unit assumed here. Also, for fertilizer work, it should be recalled that much of the additional airplane cost at high application rates was due to ferrying. In ground application, it is assumed that no ferrying of the equipment is involved, since materials are delivered by access roads to the sides of the field. Nevertheless, for high application rates, costs for ground equipment should include the trucks used to make such deliveries since this could increase operating costs significantly. For example, the capacity of the 6000 Hi-Cycle Sprayer is between the AgWagon and the Turbo Thrush, which required much ferrying for fertilizer application.

In summary, based on this simple comparison with ground equipment, it appears that a future large agricultural airplane could be made economically competitive with ground equipment, although surface machinery is still probably less expensive for most application rates. This tentative conclusion assumes a rather high utilization of airplanes compared to ground equipment, which would be a critical factor in the economic success of aerial application. It is apparent that because no overwhelming cost saving could be expected, a need must exist for the unique advantages of aerial application -- independence of terrain and field conditions, and speed and timeliness of application. An example of where aerial application may be advantageous, particularly in developing countries, is the case where fields are inaccessible to ground equipment due to terrain or long distances. Although this reason was cited for the rapid growth of aerial fertilization in the USSR (Ref. 2), there is no conclusive evidence that inaccessibility of fields is characteristic of developing countries, or of any crop with the exception of rice. Future breakthroughs in double-cropping could make aerial application a necessity if ground equipment proves harmful to emerging seedlings. More research into forest fertilization is also necessary before the requirement for larger airplanes can be determined (Ref. 37). Since ground equipment is unsuitable for this application, high-volume work in forestry has typically been handled by large, surplus aircraft adapted to spraying. If adaptation of such aircraft to dry bulk applications is not feasible, a large ag-aircraft might find a role in forestry. Additional factors affecting the choice of application technology will be discussed in the case study.

Aircraft Projections for Advanced Applications Scenario

The operational analysis provides a comparison of airplanes and technology levels (present vs future) which can be used to modify the nominal fleet projections presented earlier. Modification of those projections is particularly important in the advanced scenario where a significant shift to bulk applications is hypothesized because such a shift would affect the economic and operational viability of large ag-aircraft. Therefore, a method was developed to ascertain the impacts of the new-technology airplanes on fleet projections in the advanced scenario. The analysis was applied only to the free world market regions because it is not expected that the communist nation markets would be open to US manufacturers during the forecast period.

Field Size

The method of approach is best decribed by the example of the US market because the only means of obtaining a quantitative verification of the approach is with respect to US data. To use charts of the type presented in Figs. 41-48, it is necessary to have specific field size data, since field size and application rate are the primary variables which delineate the economics of the candidate airplanes. Expanding on some of the data presented earlier, the two upper curves in Fig. 49 show distributions of farm holding and cropland harvested in the US in 1974. These distributions are based on data from Ref. 28. Farm holdings refer to land classified as agricultural, but this category includes pastures and fallow land. Cropland harvested is more specific in that it includes only that part of agricultural land on which crops were harvested in 1974.

The distributions in Fig. 49 show the percentages of area in each category which exceeded the corresponding points on the abscissa, i.e., the percentages of area in holdings larger than a particular size. Field size data are not available, but it is obvious that the field size distribution must be well below the farm and cropland distributions because most farm holdings are divided into numerous fields, at least some of which will not have the same crop. However, it is also apparent that the field-size distribution should have the same basic form as the other curves, which can be described by the equation

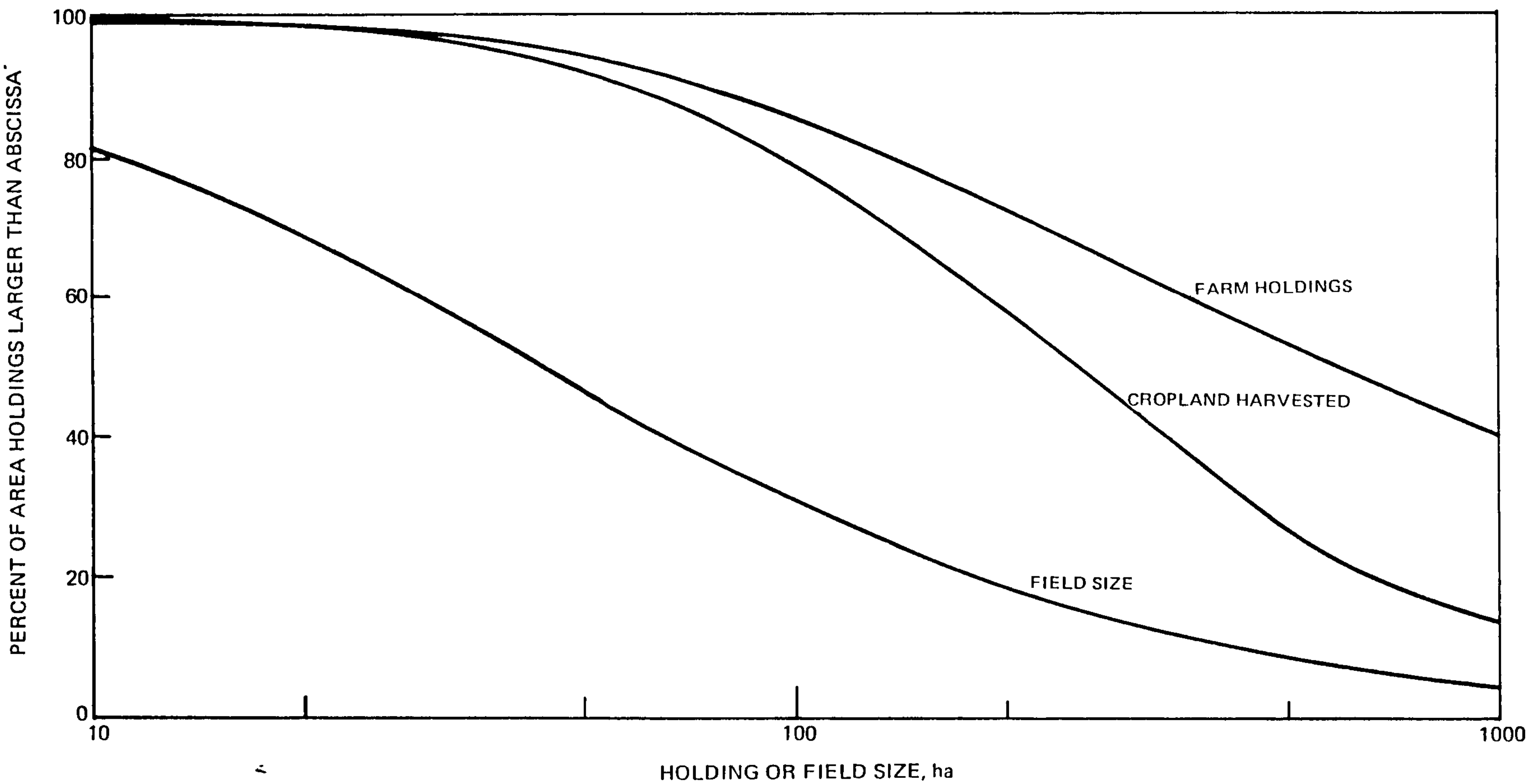
$$P = \frac{K}{K+f}$$

where P is the fraction of area in holdings larger than the field size, f, and K is a constant. This equation guarantees both that P will approach unity as field size goes to zero, and that it will go to zero as field size increases without limit.

To determine the appropriate value of the constant K, it is necessary to calibrate the equation against present US fleet and applications data. It was shown earlier that the US fixed-wing fleet presently consists of 58 percent small aircraft (under 1700 kg take-off weight), 19 percent medium-size aircraft (between 1700 and 2700 kg), and 23 percent large aircraft (over

DISTRIBUTION OF US FARM HOLDING AREA

1974



79–01–255–15

FIG 49

2700 kg). Using the format of the operations analysis, this fleet breakdown was reproduced by the decision process shown in Fig. 50. For fields smaller than f_A, small aircraft were assumed to be the proper choice, for fields between f_A and f_B, medium-size aircraft were selected and, for fields larger than f_B, large aircraft were selected. This selection process was repeated for application rates characteristic of three types of applications: 15 kg/ha for insecticides and fungicides, 75 kg/ha for herbicides, dessicants, and defoliants, and 200 kg/ha for fertilizers and seeds. The calculations were made for an average utilization characteristic of present-day operations (400 hr/yr)*, and the Pawnee, AgWagon and Turbo Thrush were used to represent present-day small, medium and large aircraft, respectively. Furthermore, based on Fig. 39, the following weighting was imposed to reflect the breakdown of US applications (by area treated) in each of the above categories:

Insecticide/Fungicide (I/F)	58%
Herbicide/Defoliant/Dessicant (H/D/D)	26%
Fertilizer/Seed (F/S)	16%

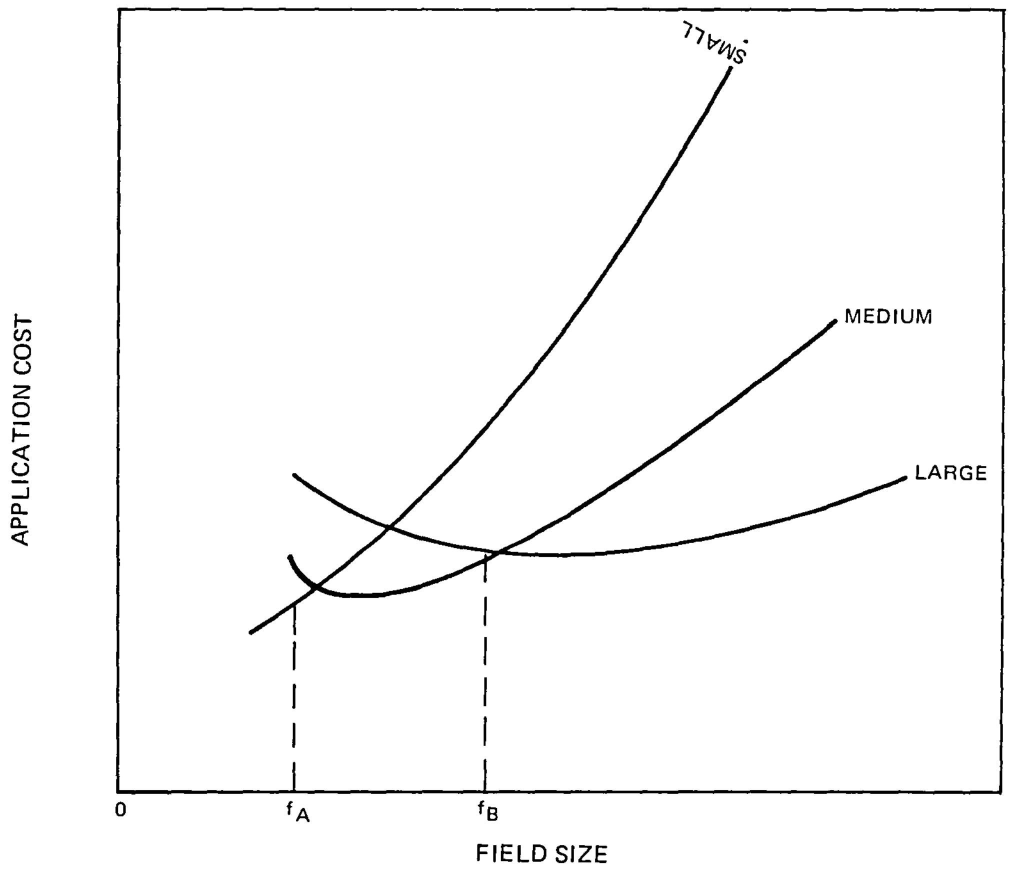
The result was a required value of K = 45 to closely reproduce the US fleet breakdown. The field-size distribution in Fig. 49 was calculated with this value.

Comparing the three distributions, it was found that the ratio of farm size to cropland size varied from about 1 to 3 (high ratio applies to low percentage of holdings), and that the ratio of cropland size to field size varied from about 4 to 8. These ratios imply that: 1) the smaller the farm, the fewer the crop and field divisions, and 2) farms are divided into many more fields than crops. Over the most interesting region of the curves (fields larger than 25 ha), a value of about 5 is appropriate for the field-to-cropland size ratio.

Since farm holdings (and, therefore, croplands and fields) are increasing in size in the US, as was shown in Fig. 22, the field-size distribution in Fig. 49 cannot be used for fleet projections in the year 2000. It is necessary to include the effect of increasing field size with time. A summary of historical and projected data relative to US agriculture appears in Fig. 51, including the field size projection for the year 2000. Based on distribution of fields, and using the advanced applications figures in Table 14, the US fleet breakdown was revised to incorporate the effect of new technology, as represented by the inclusion of the Improved AgWagon and AGB-7-TB1 to the airplane decision process. A calculation was also made for the nominal scenario, using only the existing airplanes, and assuming the nominal values for future applications practice (I/F - 48 percent, H/D/D - 30 percent, F/S - 22 percent). The results are summarized in Table 19, along with the 1976 breakdown for comparative purposes.

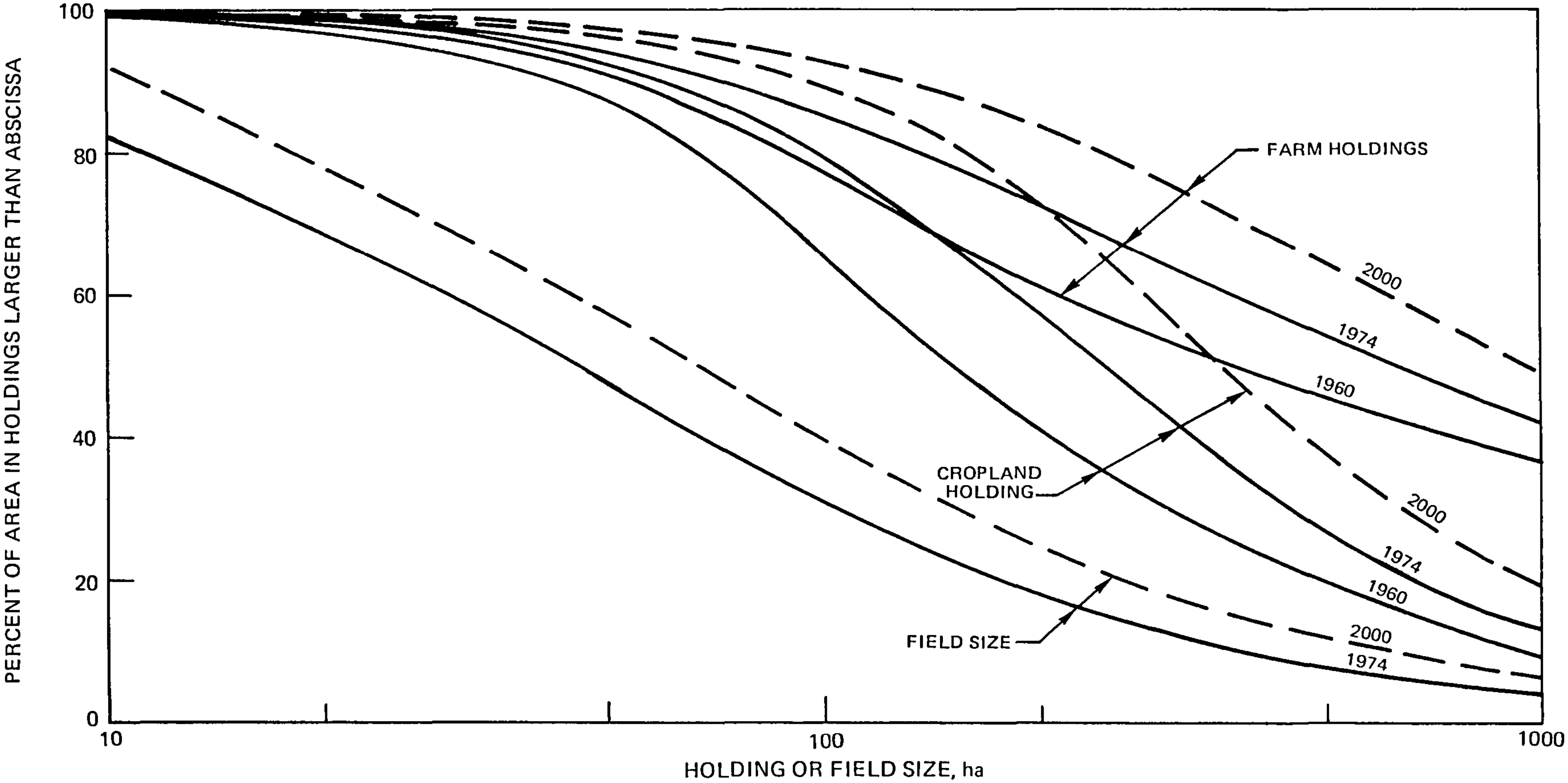
*It was shown in Fig. 25 that 300 hr/yr is the fleet average, but the utilization of dedicated ag-aircraft is probably higher.

AIRPLANE DECISION PROCESS



79–01–255–31

PROJECTION OF US FARM HOLDING AND FIELD SIZE DISTRIBUTIONS



79–01–255–27

FIG 51

It was shown earlier that the trend to larger aircraft is strong in the US market. The nominal scenario predicted a significant shift from small (S) to medium (M) and large (L) aircraft. In Table 19, the 21 percent decrease in small airplanes results in almost equal increases in both the medium and large categories, with the result that large airplanes attain the biggest share. Under the assumptions of the advanced scenario, the shift is far more pronounced. The percentage of small aircraft is less than 1/3 of its 1976 value, reflecting both the de-emphasis of insecticide/fungicide applications and the further growth of fields. The medium-size percentage is almost the same as in the nominal scenario, primarily because the Improved AgWagon prevents some of the shift which would have occurred without its technological improvements. Most important is the emergence of the very-large (VL) category, represented by the AGB-7-TB1, which penetrates significantly into the large fertilizer market.

Free World Market

Each world region can be characterized by its own field-size distribution, as was shown earlier in Table 6. In order to repeat the airplane decision process for other free-world markets, field-size data for each region were assembled and projected to the year 2000. Data from the 1960 FAO World Census of Agriculture (Ref. 25) were aggregated into the major markets of the Other Developed Nations and LDC groups, as shown in Figs. 52 and 53. It is clear from these charts that some regions are like the US in their concentration of farm and cropland in large holdings, while much smaller holdings dominate in some other regions. In general, the developed nations, with the exceptions of Japan and Western Europe, have high percentages of large holdings. Conversely, the LDC groups are characterized by smaller holdings, although the Latin American regions are closer to the developed nations than either Asia or Africa. These distributions were uniformly increased according to the growth rates in Table 6, and cropland holdings were converted to field sizes by the same ratio (5) as for the US. The field size distributions in Figs. 54 and 55 were then used to make airplane allocations, as in the US example, for the advanced scenario. These results appear in Table 20 for each region, and the aggregation to major markets is provided in Fig. 56.

Some important factors contribute to the differences in fleet breakdowns in Fig. 56. The high percentages of medium- and very-large aircraft in the Other Developed Nation group, for example, are direct results of the dominance of Oceania and Canada, both of which have high percentages of large fields (Fig. 54) and concentration of agriculture in crops amenable to aerial fertilization (grains) and herbicides (rangeland). By contrast, the LDC group has high percentages of small and large aircraft because it is dominated by the Latin American region, for which crops with high insecticide

TABLE 19

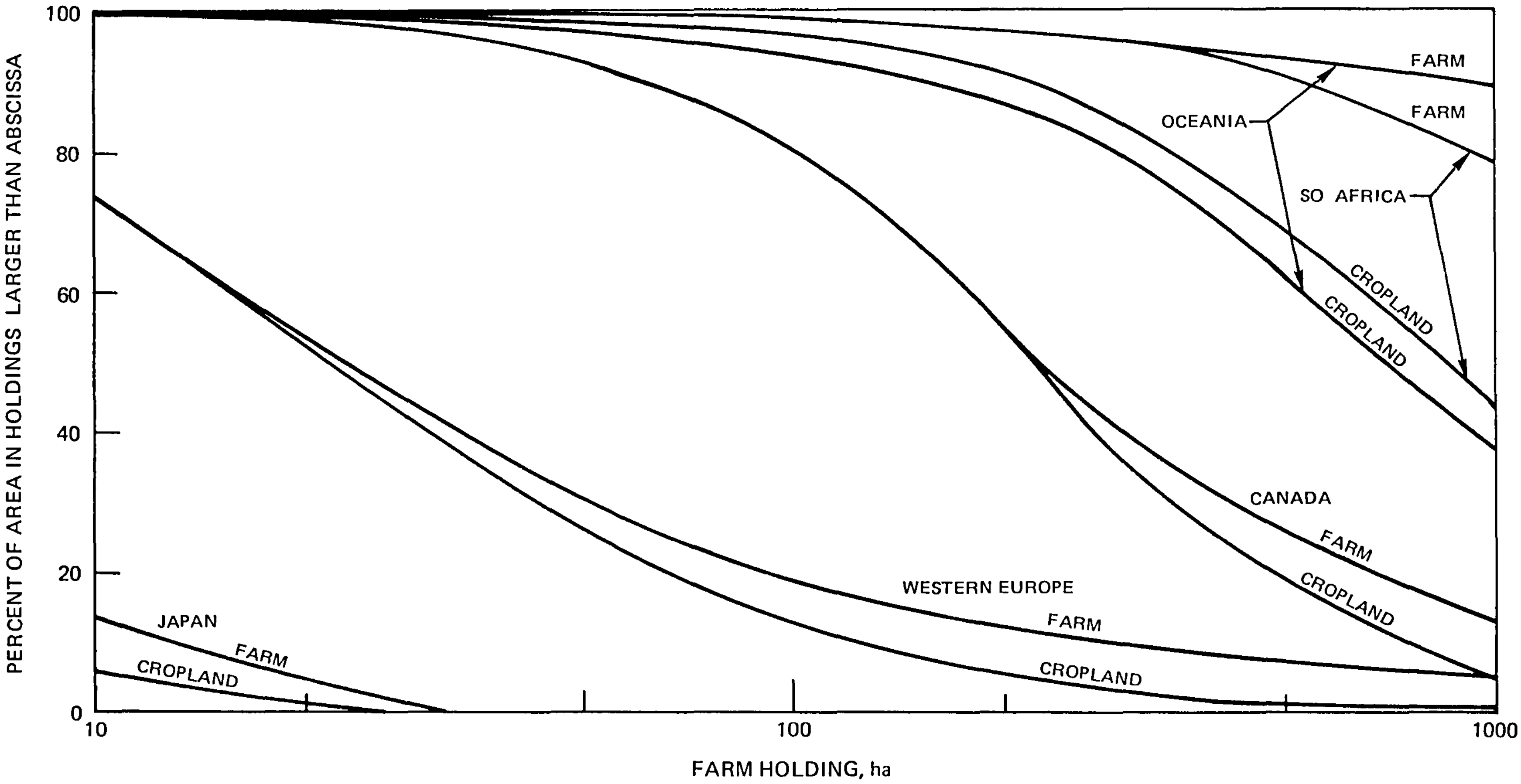
COMPARATIVE US FLEET BREAKDOWNS

Application Category	Percent of Airplanes in Fleet									
	1976			2000 (Nominal)			2000 (Advanced)			
	S	M	L	S	M	L	S	M	L	VL
I/F	45	13	0	34	14	0	18	15	0	0
H/D/D	10	6	10	0	14	16	0	14	1	4
F/S	0	0	16	0	0	22	0	0	23	25
TOTAL	55	19	26	34	28	38	18	29	24	29
ACTUAL	58	19	23	32	32	36	-	-	-	-

DISTRIBUTION OF FARM HOLDING AREA

OTHER DEVELOPED NATIONS

1960



79–01–255–28

FIG 52

DISTRIBUTION OF FARM HOLDING AREA

LDCs

1960

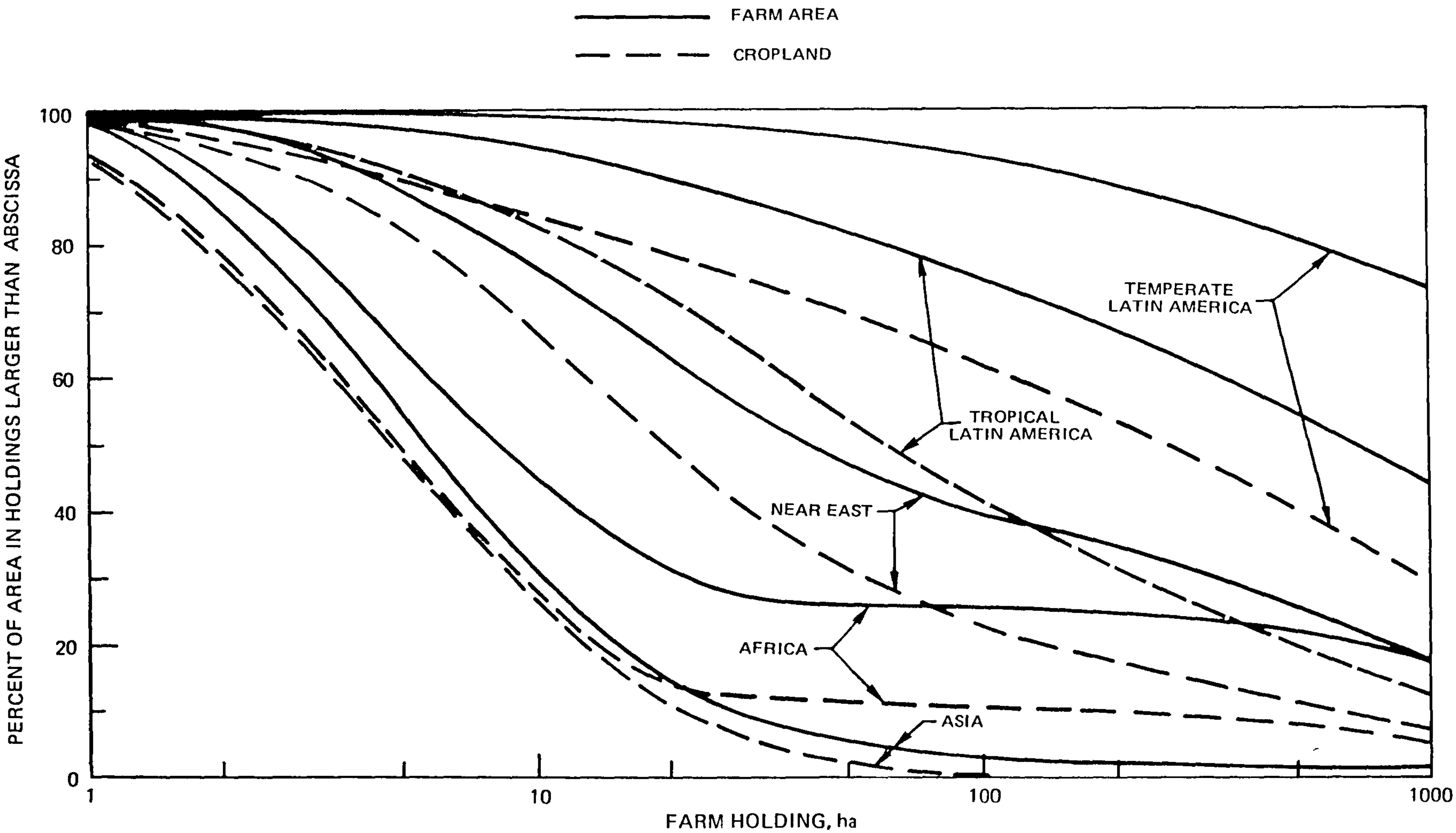
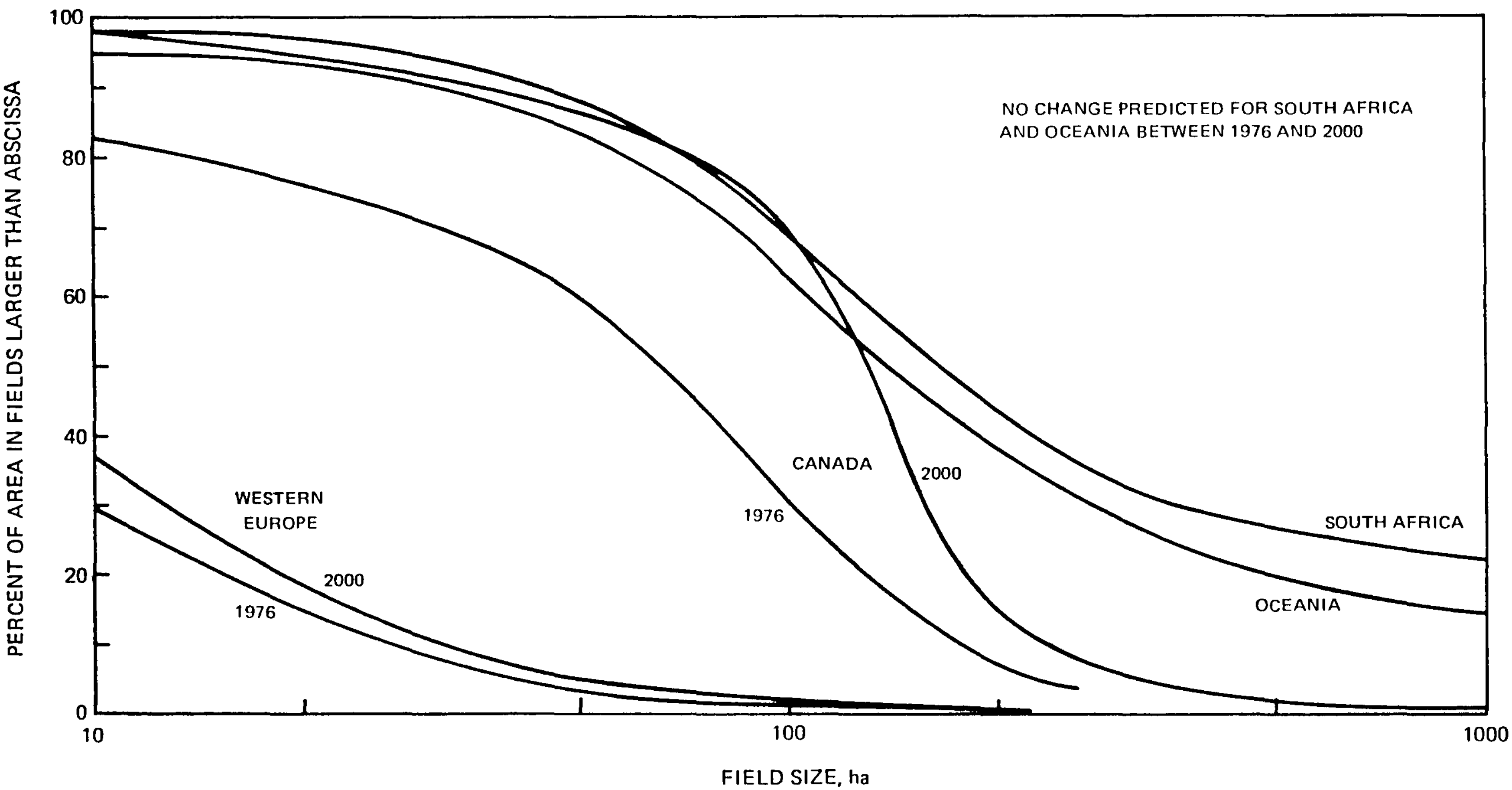


FIG 53

79–01–255–20

PROJECTION OF FIELD SIZE DISTRIBUTION

OTHER DEVELOPED NATIONS



79-01-255-29

FIG 54

PROJECTION OF FIELD SIZE DISTRIBUTION

LDCs

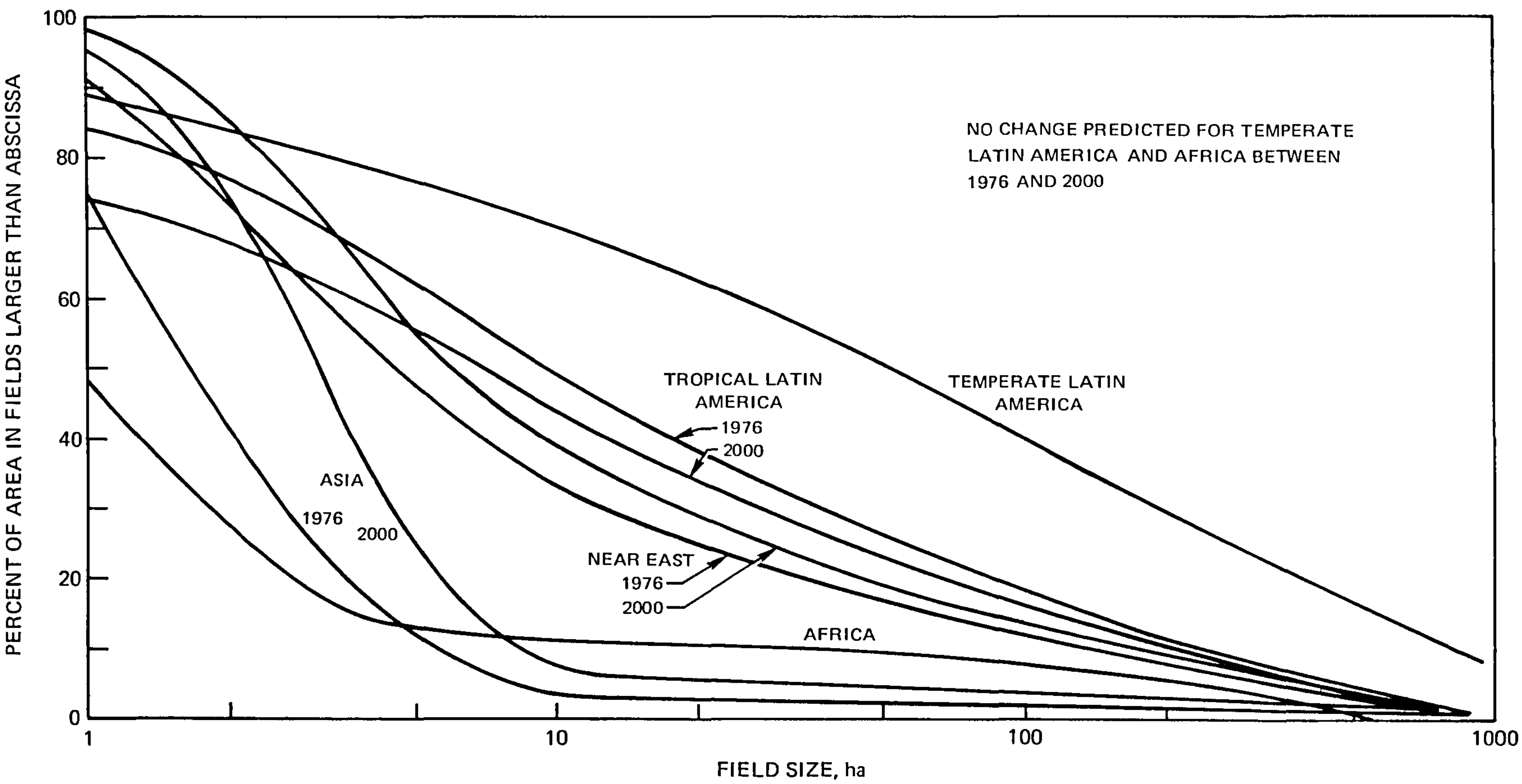
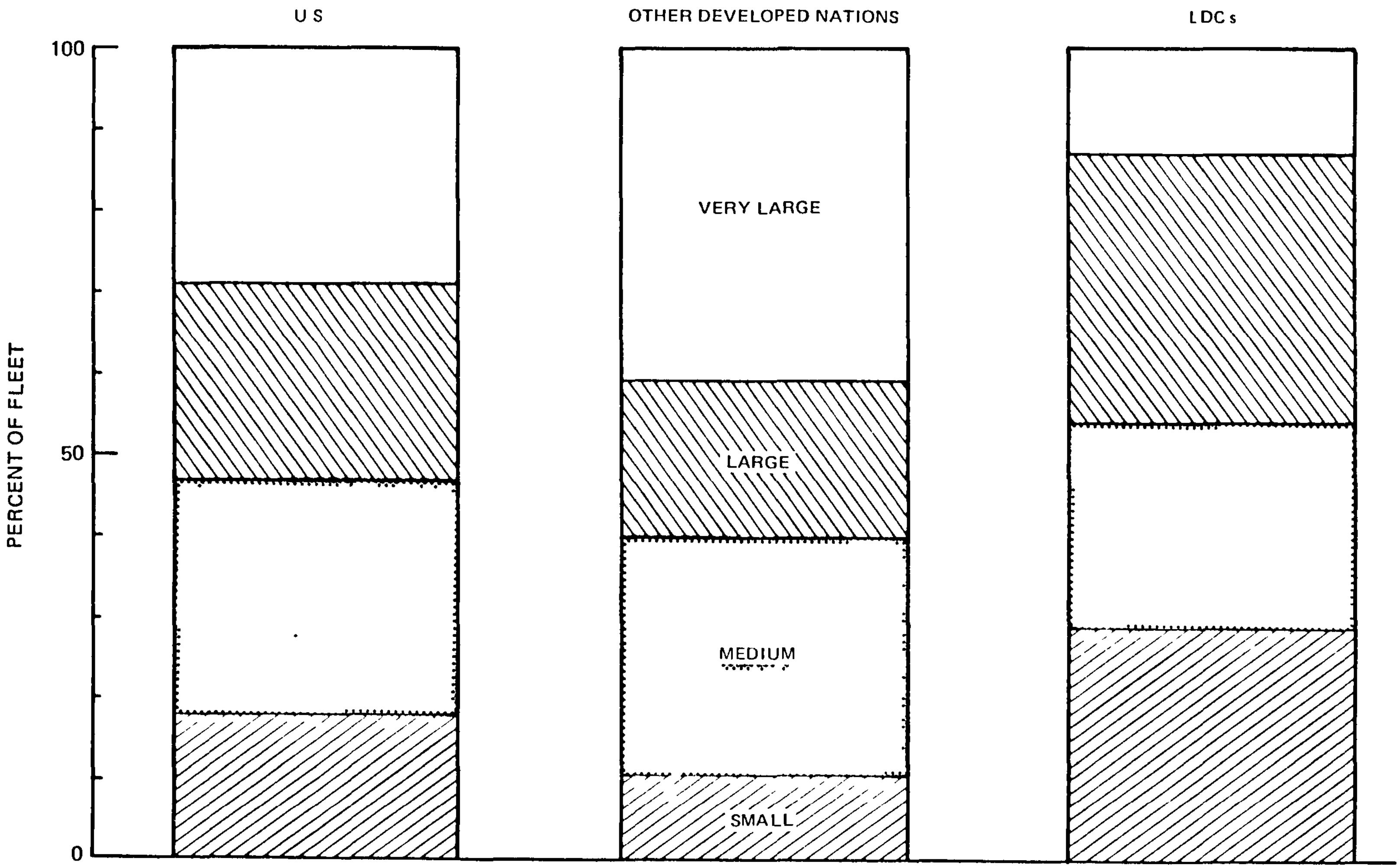


FIG. 55

79-01-255-22

FLEET BREAKDOWNS FOR FREE WORLD MARKETS

ADVANCED SCRENARIO IN YEAR 2000



79-01-274-6

FIG 56

use are prevalent (e.g., cotton, sorghum), but where fairly large fields are also the rule. These conflicting effects illustrate the complexity of the world-market picture and show the importance of analyzing it with respect to regions of compatible agriculture and land-use patterns. To provide some insight into the disparate fleet compositions in Table 20, the last two columns provide some crop and field-size factors which affect the results.

TABLE 20

SUMMARY OF FLEETS FOR ADVANCED SCENARIO

Group	Region	Percent of Fleet in Year 2000 Small	Medium	Large	Very Large	Contributing Factors: Major Ag-Air Crops in Year 2000	% Fields Larger than 100 ha
US	-	18	29	24	29	Rice Grains, Cotton	39
Other Developed							
	Oceania	7	32	13	48	Grains, Cotton, Rice	62
	W. Europe	24	20	53	3	Grains, Vegetables	2
	Canada	5	30	12	53	Grains	70
	South Africa	13	50	6	31	Cotton	69
	Japan	100	0	0	0	Rice, Vegetables, Citrus	0
	Israel	18	29	24	29	Cotton, Citrus	30
	TOTAL	11	29	19	41		
LDC							
	Mexico	39	24	28	9	Sorghum, Cotton	40
	Trop. Lat. Amer.	28	20	40	12	Cotton, Soybeans	16
	Temp. Lat. Amer.	24	34	19	23	Sorghum, Rangeland	40
	Near East	30	19	42	9	Rice, Cotton, Vegetables	14
	Asia	11	16	66	7	Rice	4
	Africa	33	19	42	6	Rice, Cotton, Dry Beans	8
	TOTAL	29	25	33	13		
Free World	-	20	28	25	27		

COLOMBIA: AGRICULTURAL AIRCRAFT CASE STUDY

To analyze more specifically the impacts which advanced agricultural aircraft might have, a case study country was selected for detailed analysis. After a selection process (see Appendix) which considered a variety of physical, economic, and social factors, Colombia was chosen based on its agricultural potential in a variety of crops and its present use of agricultural aircraft. Existing agricultural production and trends were examined and the extent of agricultural aircraft use was analyzed. During the course of the study, a visit was made to Colombia to determine the nature of current problems facing Colombian ag-air operators and to gather firsthand information concerning the agricultural sector and factors affecting future use of ag-aircraft.

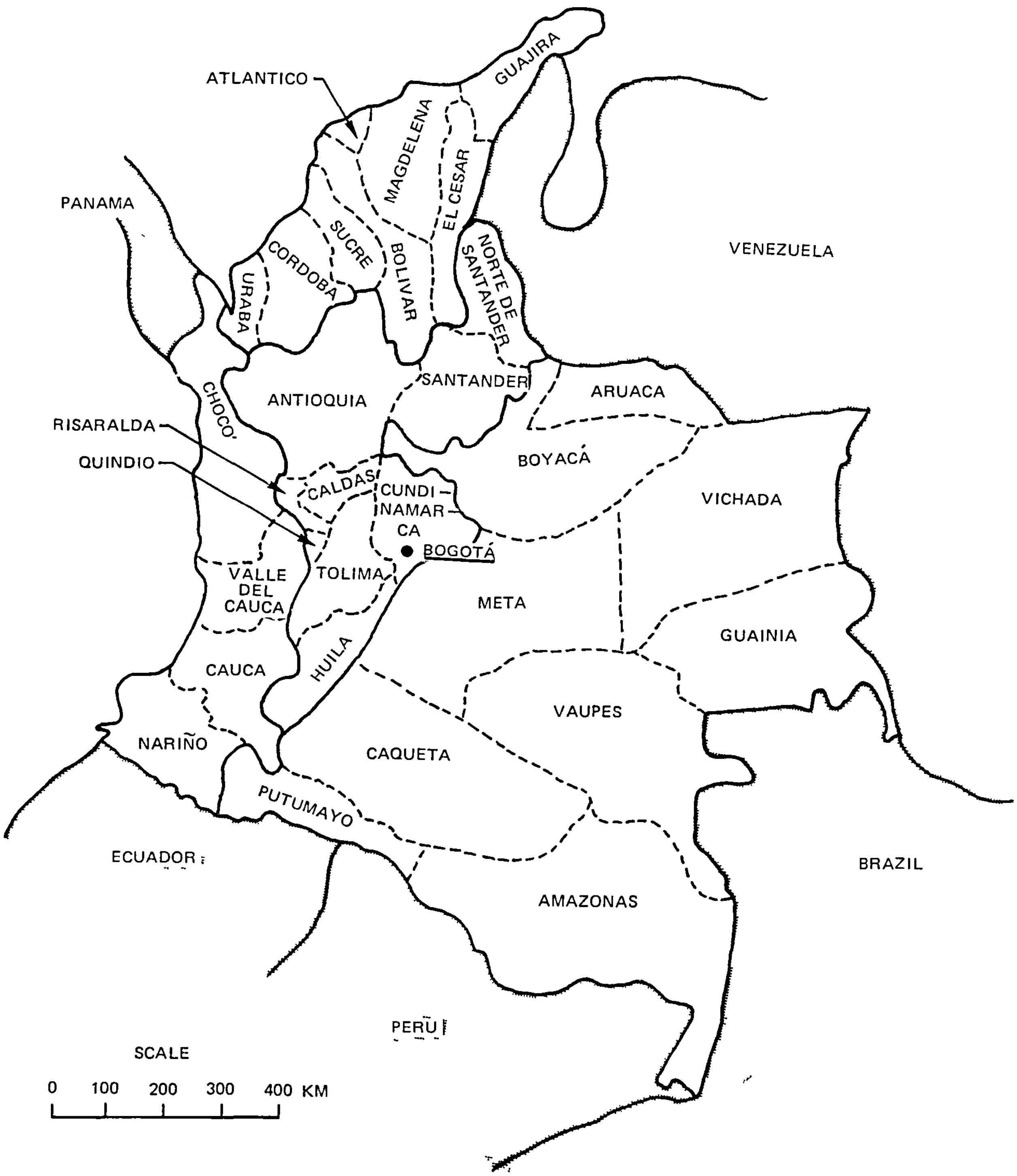
Country Description

Colombia is located in the northwest corner of South America, with coasts on both the Atlantic and Pacific Oceans. Figure 57 shows a map of Colombia indicating the principal regions and political divisions. The country is primarily agricultural and most of the population is employed in that sector. The climate and terrain are varied -- the lowlands are generally hot and have heavy rainfall. In the mountains, climate varies with altitude and becomes quite temperate in the higher elevations. The Andes mountains enter Colombia from the Equador border and split into three ranges. The capital city of Bogotá is located on an 8000-ft plateau in the Eastern Range of the Andes. Much of the farming is done in the rich, fertile valleys and plateaus, which also contain the majority of the population. The Magdalena River is the principal river and flows in the eastern valley into the Carribean. The remainder of the country is almost uninhabited and consists of a great plain known as the Llanos, extending eastward from the Andes. Toward the southeast, the area becomes a tropical rain forest and is part of the Amazon basin. Temperatures are relatively constant throughout the year in all parts of Colombia, with seasonal variations occurring in the amount of rainfall.

Coffee is Colombia's most significant crop and comprises over half of its exports. The crop grows on mountainsides at elevations between 1300 and 2000 meters. Due to the fact that it has been relatively disease-free and is grown on very small plots, there has been no aerial application on coffee plants and it is unlikely that there will be in the future. Of Colombia's other major crops, the principal ones receiving aerial applications are cotton, rice, bananas, sorghum, soybeans, and sugar cane. The main cotton-growing regions are Tolima, the Cauca Valley, and the northern coast. Rice production is distributed similarly, with the Llanos emerging as a new region of great potential. Bananas are concentrated in a small region on the Caribbean coast. Sorghum is a small but increasingly important crop, grown in the same regions as cotton and rice. Finally, soybeans and sugar cane presently represent only a very small fraction of aerial application work in Colombia.

FIG 57

COLOMBIA



79–01–274–1

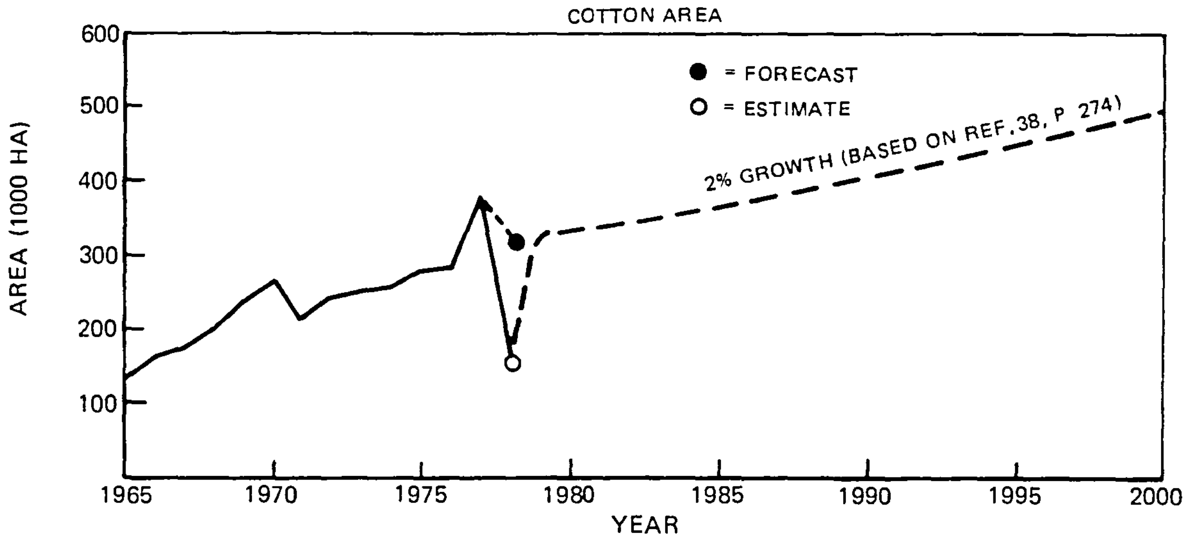
Projections of Agricultural Production and Exports

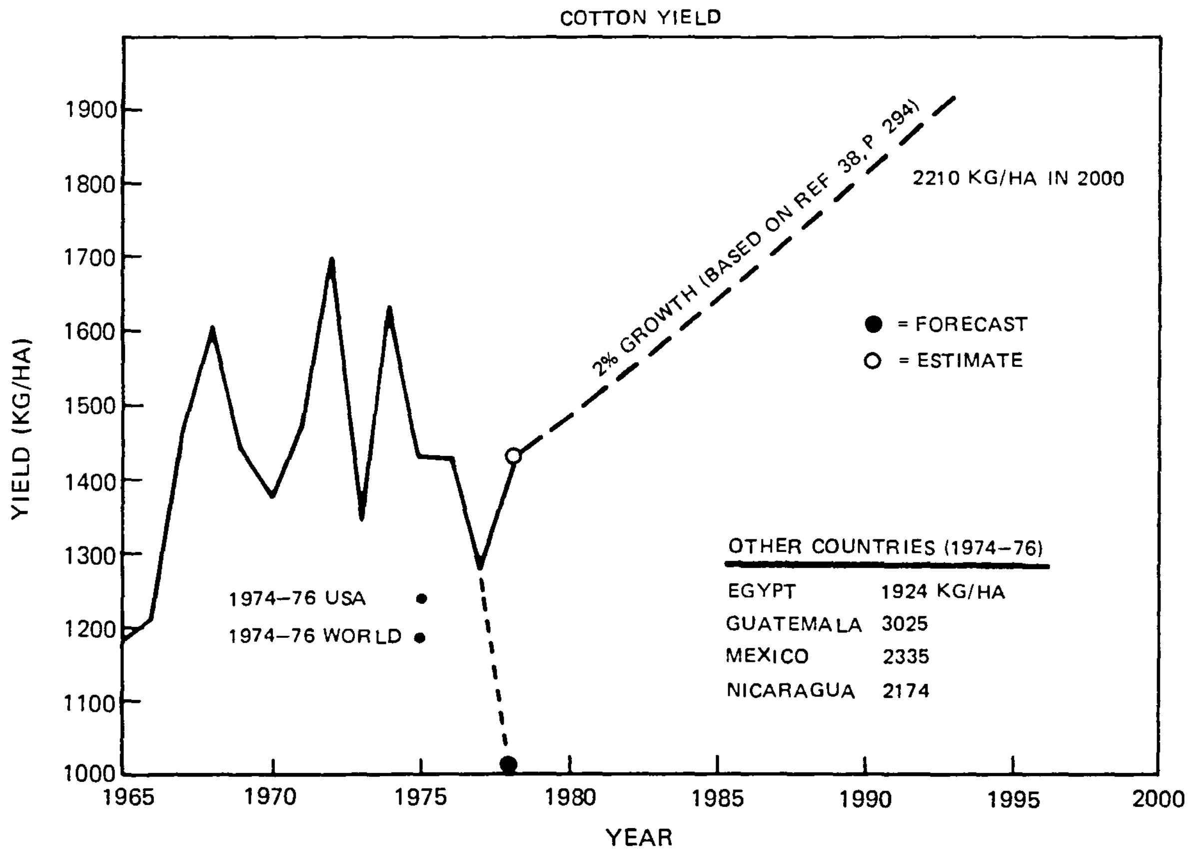
Agricultural data for Colombia (Ref. 3) were analyzed and used to make projections of crops to the year 2000. Time series data from 1965 to 1978 were plotted for the area and yield of the five major crops treated by air: cotton, rice, bananas, sorghum and soybeans. Information provided in Ref. 38 was used as the basis for extrapolating these trends to the year 2000. Data for cotton are shown in Fig. 58. Yield has been erratic, but a 2 percent growth can be expected, as suggested by past trends and comparative yields in other countries. Crop production is the product of area and yield, shown in Fig. 59 for cotton. For rice, published projections of area are rather conservative, so a more realistic extrapolation was made, as seen in Fig. 60. Along with a modest increase in yield, this results in the 3 percent annual growth of production indicated in Fig. 61. This growth rate is about the same as the expected population growth rate. Although less data for bananas were available, the estimates in Figs. 62 and 63 seem reasonable on the basis of past trends. For sorghum, extrapolation of time series data on area is much more conservative than the 10 percent growth rate from Ref. 38. The high growth rate was postulated to account for shifting emphasis from corn to sorghum in the manufacture of concentrates, due to sorghum's higher yielding ability and its adaptibility to mechanization. A similar phenomenon is taking place with soybeans, shown in Figs. 66 and 67. In this case, the driving factor is import substitution. Although soybean imports appear to be small in Fig. 67, much of the imports are in processed form (oils), which accounts for the low weight. The variation in projected area is due to uncertainty in the percapita consumption of edible oils and fats.

To estimate foreign exchange earnings from increased agricultural production, it was necessary to project the export value of the major crops. Cotton, rice and bananas have been, and will continue to be, the primary export crops. The weight, value and unit value of the exports of these crops were tabulated for the years 1971-1976 (Ref. 39) using an average for each crop, as well as a breakdown by components (e.g., shelled rice, polished rice, rice for seed, etc.). The future values of these crops were projected in current dollars (assuming past trends of inflation continue) and the export potentials (in current US $) were obtained by multiplying the future values by the projected weights obtained previously. Actual exports from 1971 to 1975 were then plotted (Ref. 40) and the ratio of actual exports to potential exports determined. This ratio was then projected and used to determine the value of exports for each of the crops, as follows:

10^6 Current US $

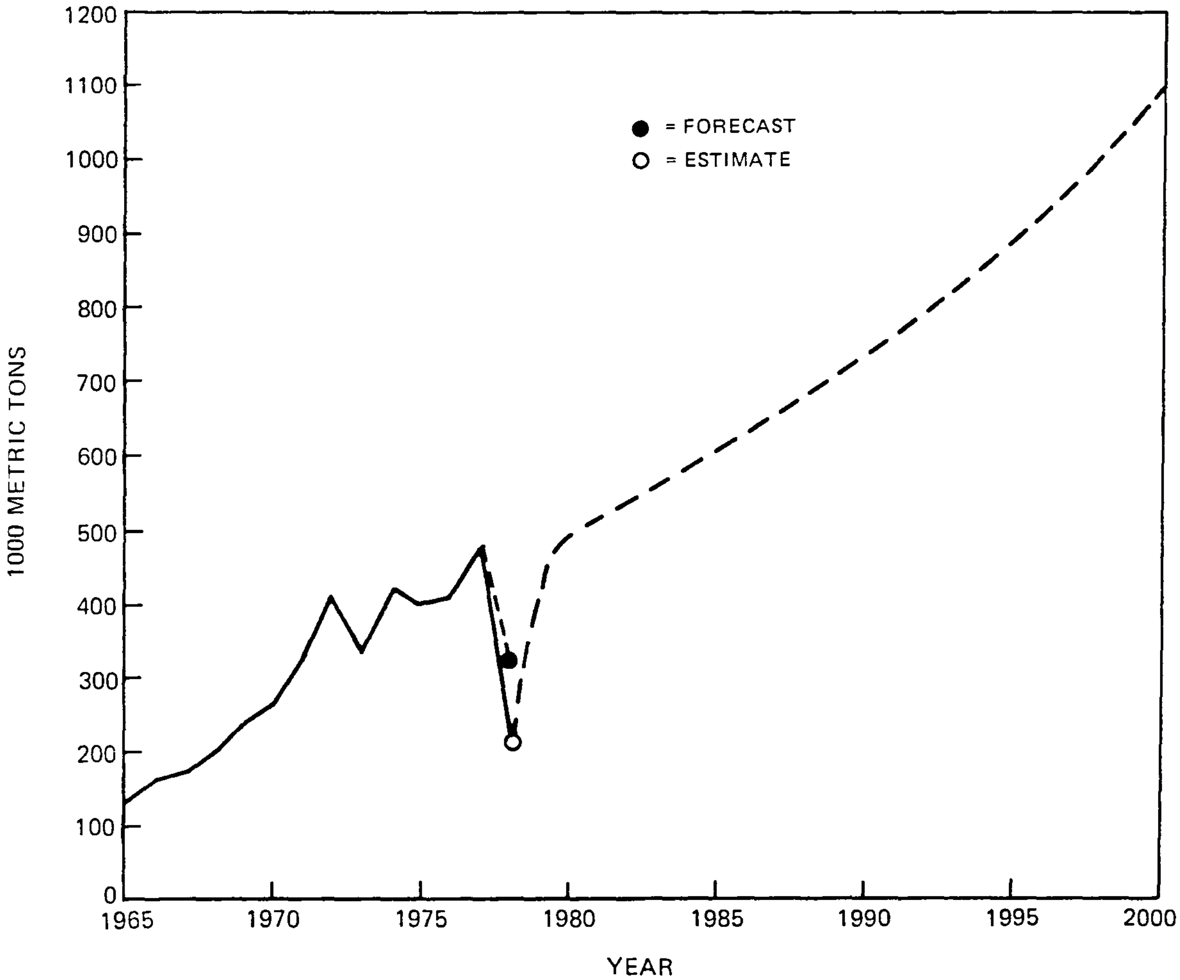
	1975	1980	1985	1990	1995	2000
Cotton	76	135	220	357	562	824
Rice	22	54	125	230	380	570
Bananas	32	87	203	285	367	432
Total	130	276	548	872	1309	1826


COTTON AREA
● = FORECAST
○ = ESTIMATE
2% GROWTH (BASED ON REF.38, P 274)
AREA (1000 HA)
600
500
400
300
200
100
1965
1970
1975
1980
1985
1990
1995
2000
YEAR


COTTON YIELD
2% GROWTH (BASED ON REF 38, P 294)
2210 KG/HA IN 2000
● = FORECAST
○ = ESTIMATE
OTHER COUNTRIES (1974–76)
EGYPT 1924 KG/HA
GUATEMALA 3025
MEXICO 2335
NICARAGUA 2174
1974–76 USA
1974–76 WORLD
YIELD (KG/HA)
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
1965
1970
1975
1980
1985
1990
1995
2000
YEAR

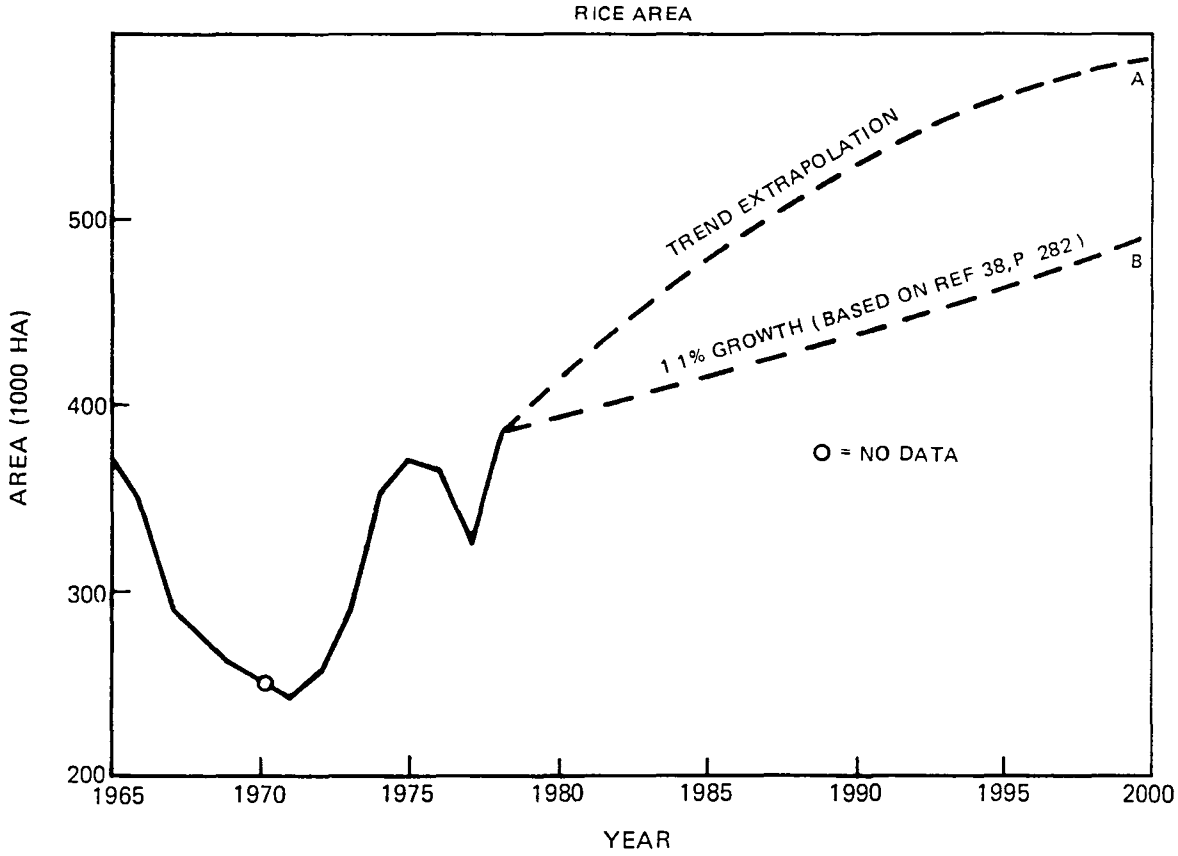
78–12–19–12

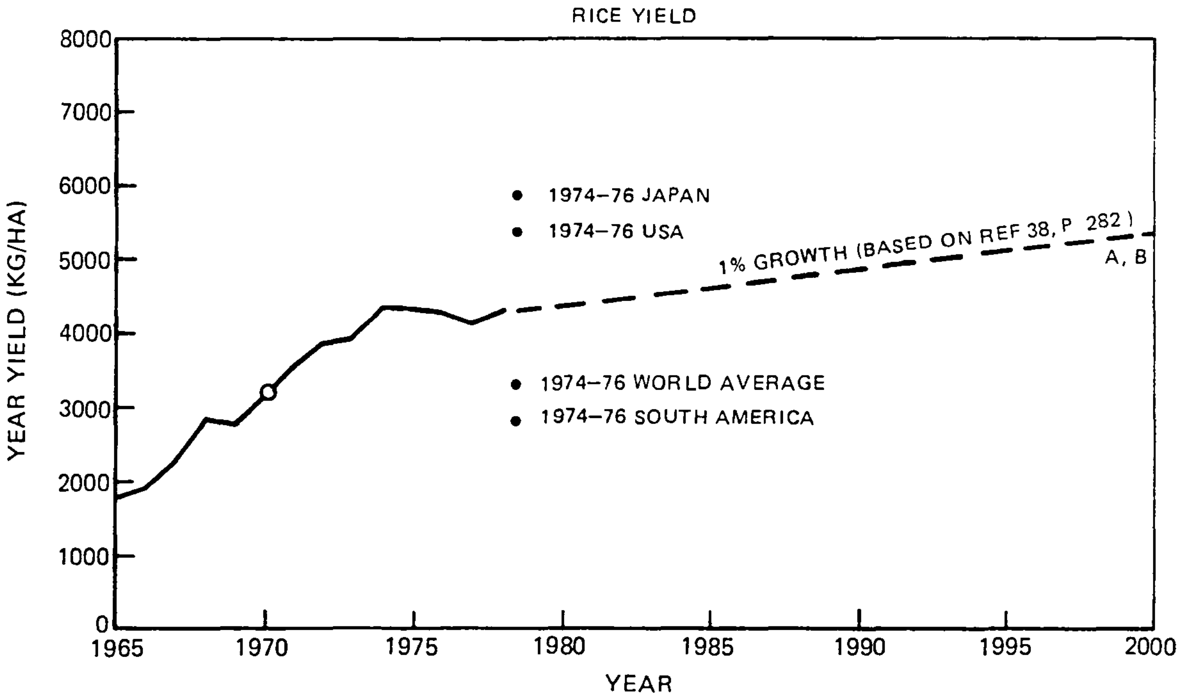
COTTON PRODUCTION



78–12–19–2

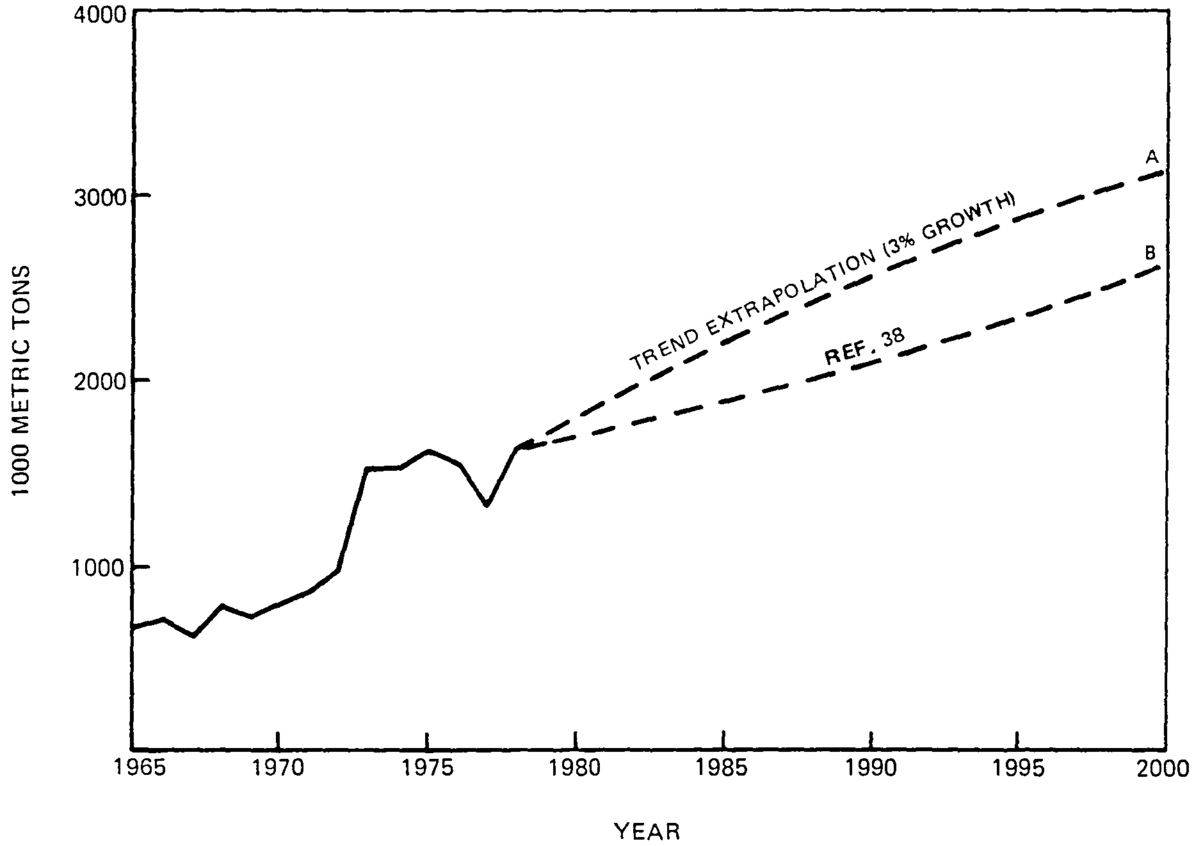
FIG. 60





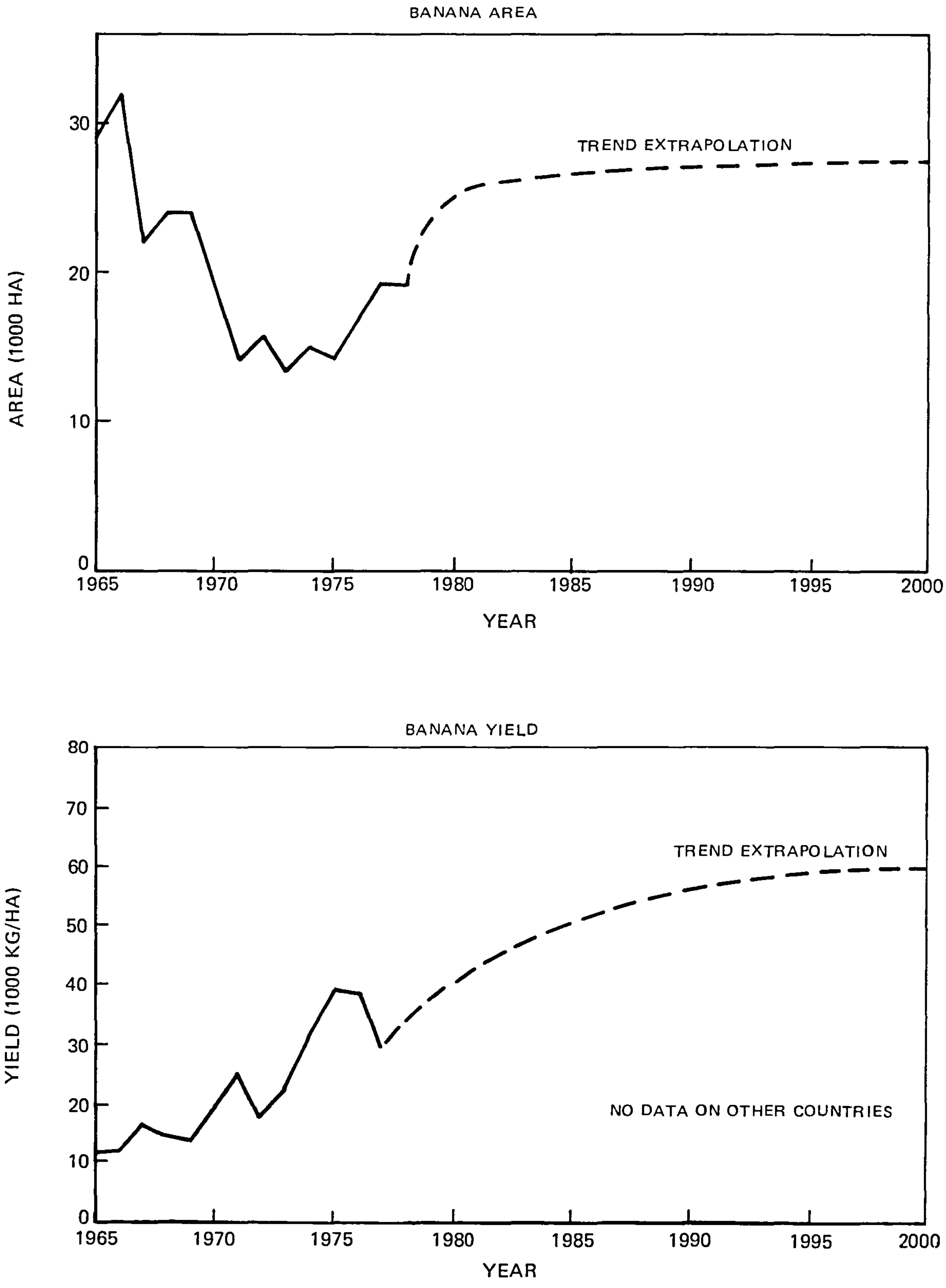
78–12–19–10

RICE PRODUCTION

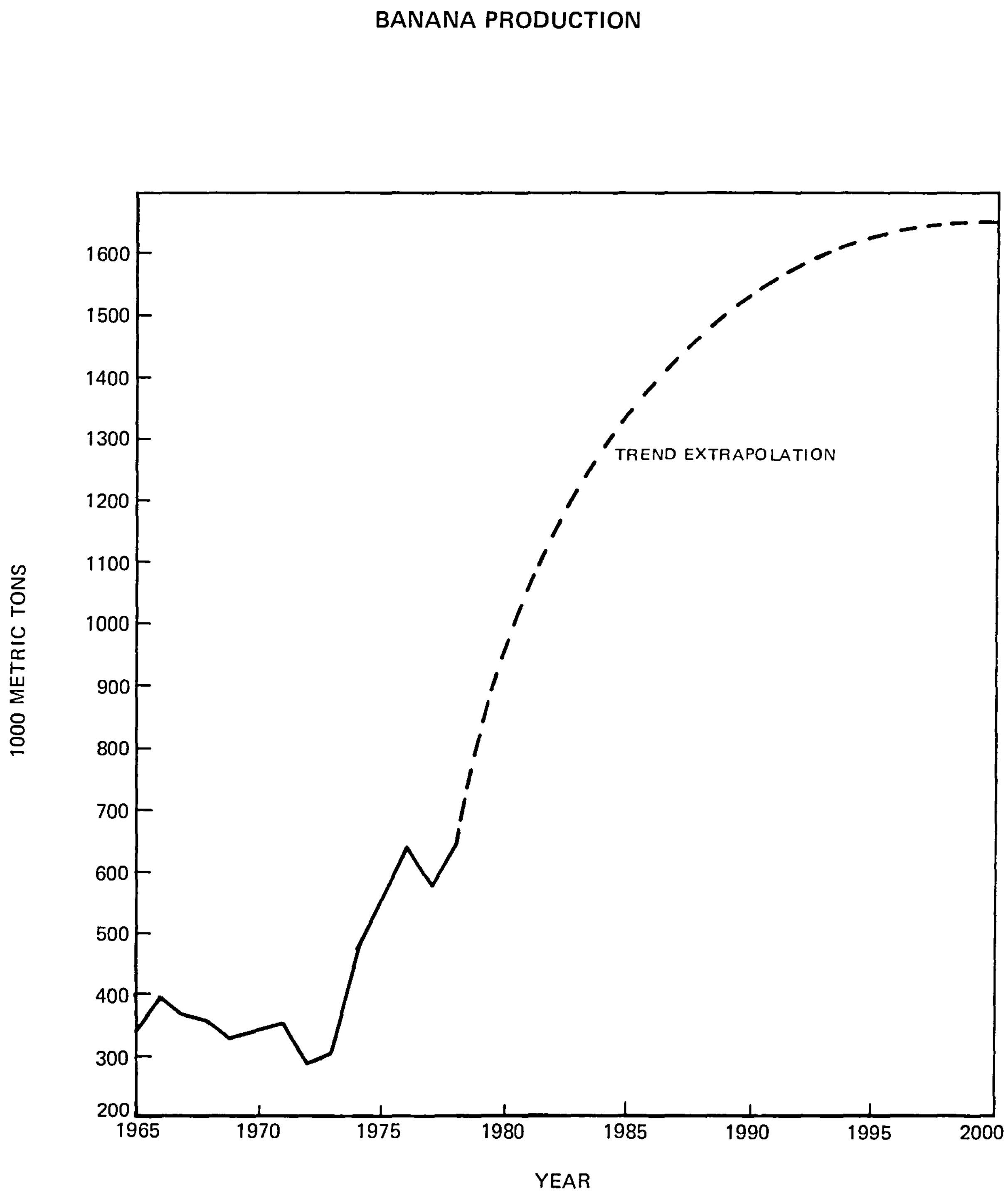


78–12–19–6

FIG 62



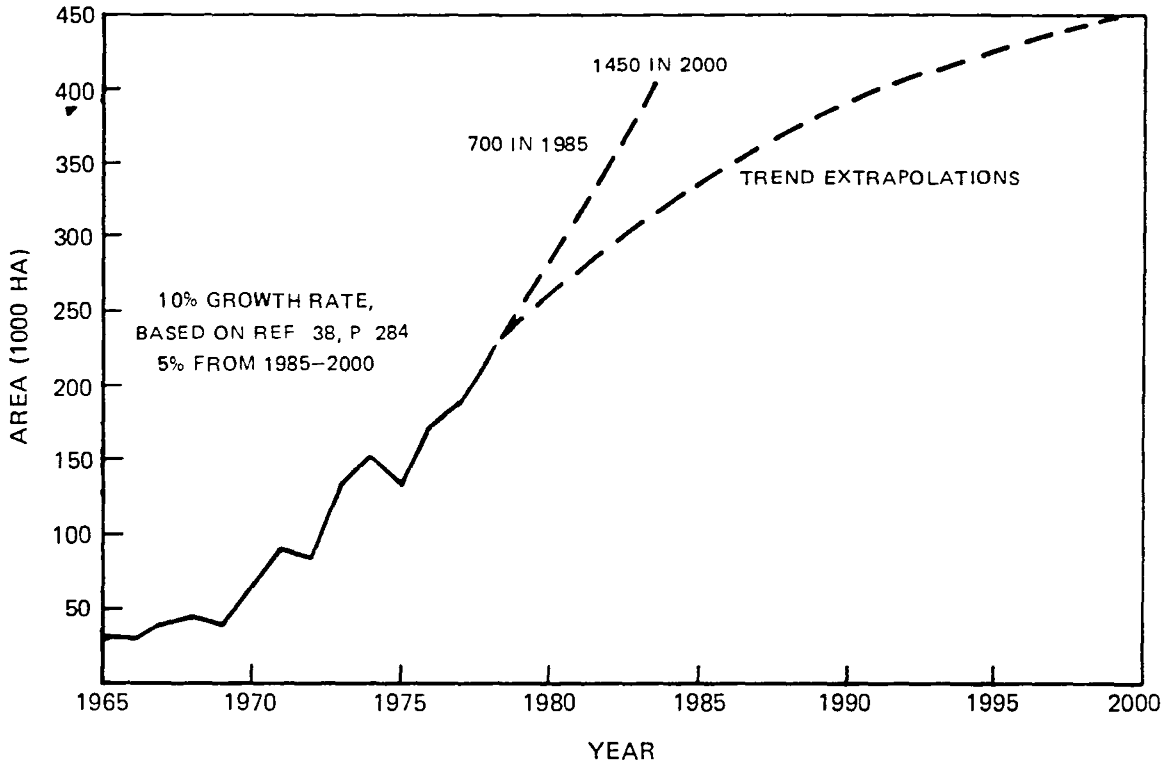
78–12–19–4


BANANA PRODUCTION
1000 METRIC TONS
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
TREND EXTRAPOLATION
1965
1970
1975
1980
1985
1990
1995
2000
YEAR

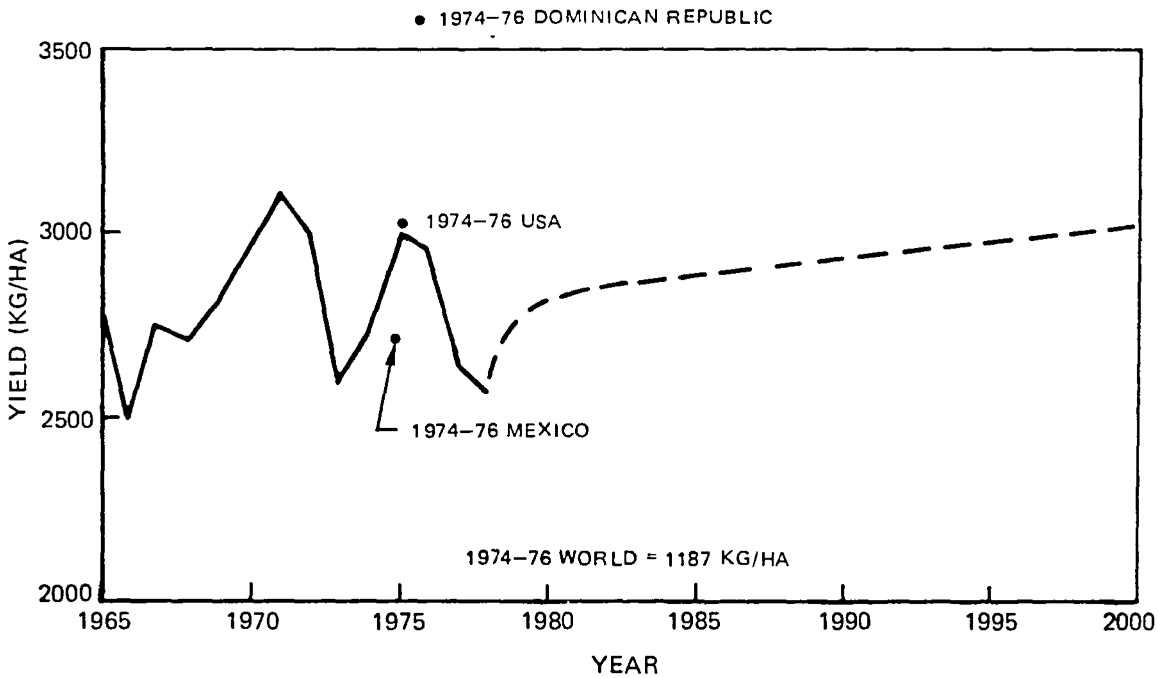
78–12–19–8

FIG 64

SORGHUM AREA

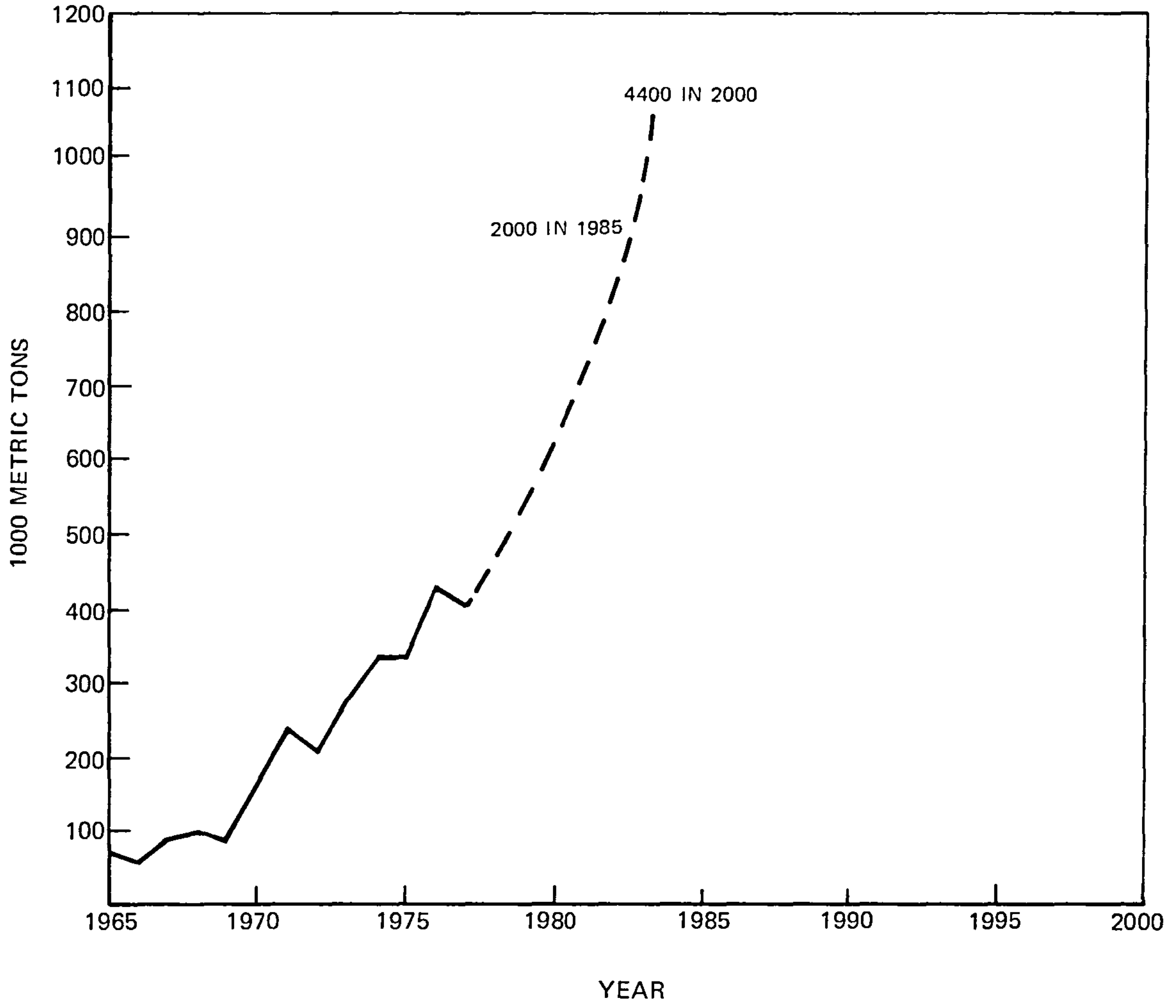


SORGHUM YIELD

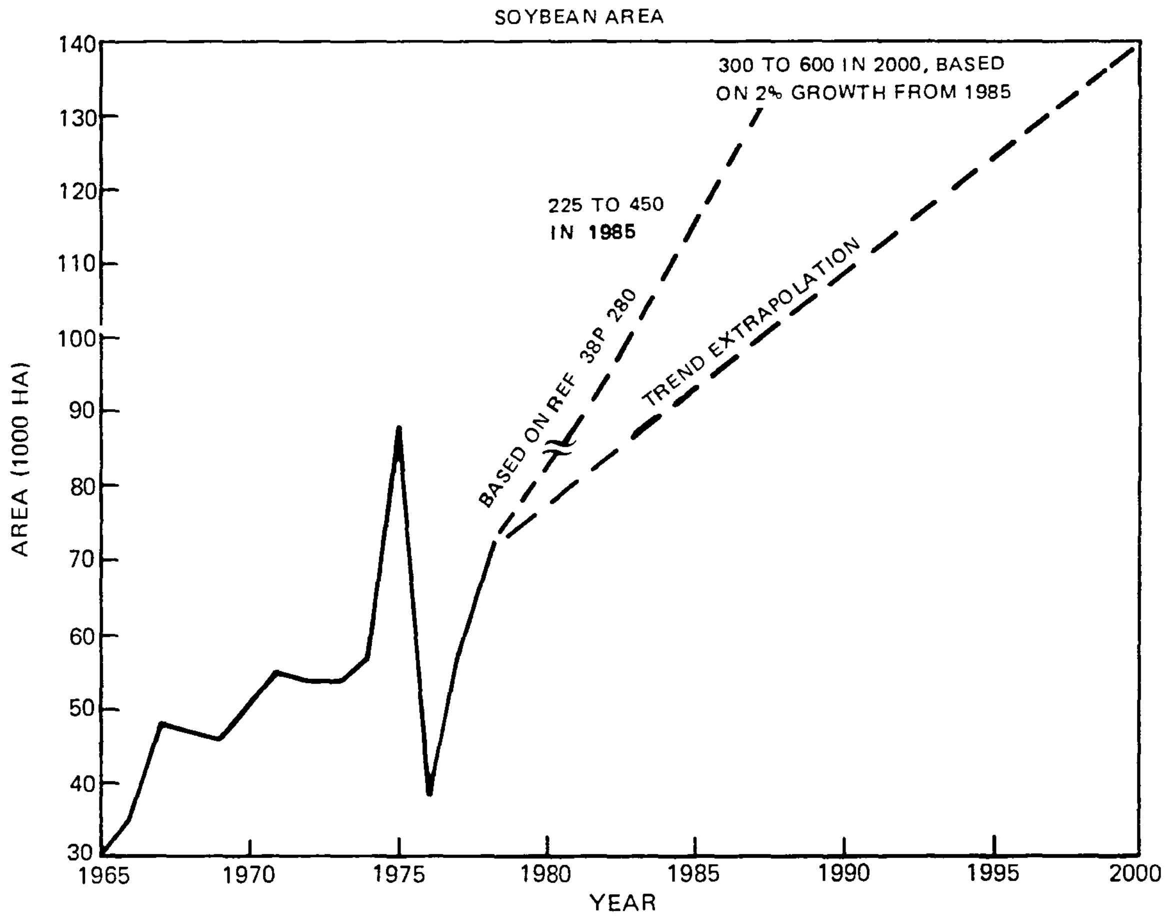


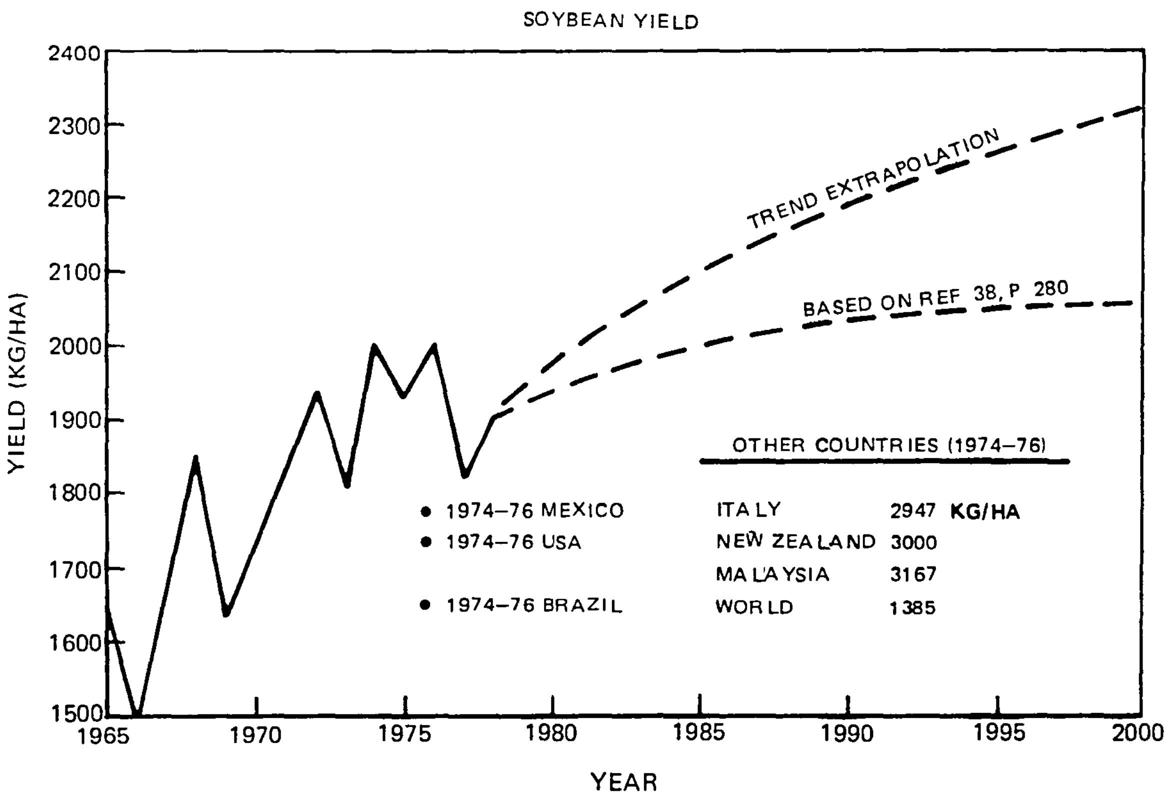
78–12–19–5

SORGHUM PRODUCTION



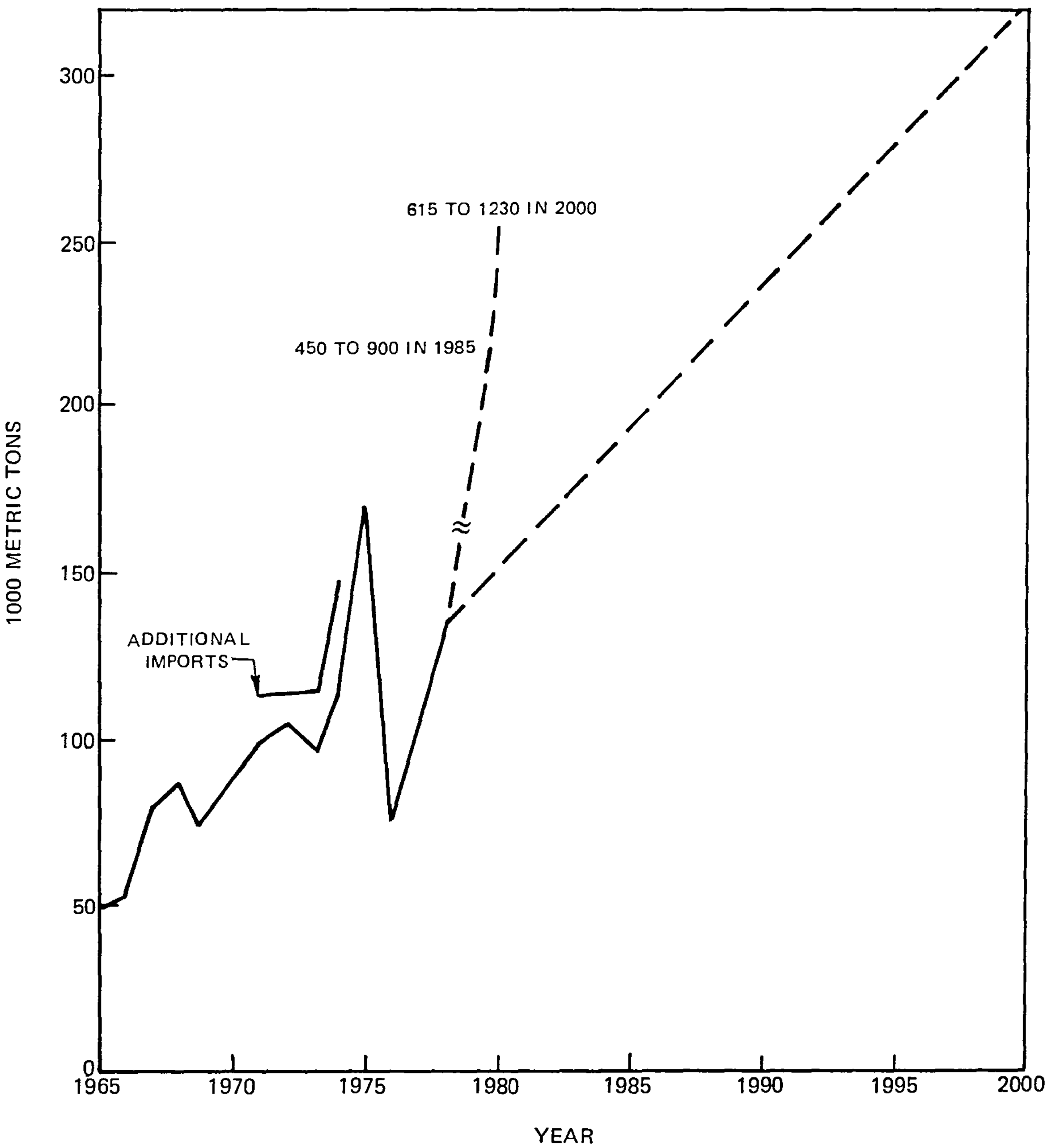
78–12–19–9


SOYBEAN AREA
AREA (1000 HA)
140
130
120
110
100
90
80
70
60
50
40
30
1965
1970
1975
1980
1985
1990
1995
2000
YEAR
300 TO 600 IN 2000, BASED
ON 2% GROWTH FROM 1985
225 TO 450
IN 1985
BASED ON REF 38P 280
TREND EXTRAPOLATION


SOYBEAN YIELD
YIELD (KG/HA)
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1965
1970
1975
1980
1985
1990
1995
2000
YEAR
TREND EXTRAPOLATION
BASED ON REF 38, P 280
1974–76 MEXICO
1974–76 USA
1974–76 BRAZIL
OTHER COUNTRIES (1974–76)
ITALY 2947 KG/HA
NEW ZEALAND 3000
MALAYSIA 3167
WORLD 1385

78–12–19–11

SOYBEAN PRODUCTION



78–12–19–7

Although the values are given as current US $, they can be deflated by the expected inflation rate to obtain real exchange earnings. These projections are very crude but are useful to compare the relative importance of each crop. The cotton share is expected to decline from 58 percent in 1975 to about 40 percent of the three-crop total in 1985 and rise slightly thereafter. Rice should experience a gradually increasing share from 17 percent to about 30 percent in the year 2000. Bananas will continue to grow, peaking in 1985 and then declining to their current share.

Aerial Application in Colombia vs the US

Agriculture in Colombia has many similarities with that of the US. However, there are structural differences in the ag-air industries in the two countries as well as some differences in the crops which are treated. Recent trends in aerial applications in Colombia are shown in Figs. 68-71, which depict fleet size, utilization of aircraft, and area treated, for the major crops. Although the estimate of fleet size has varied considerably (Fig. 68), total hours flown have risen throughout most of the period shown (Fig. 69).

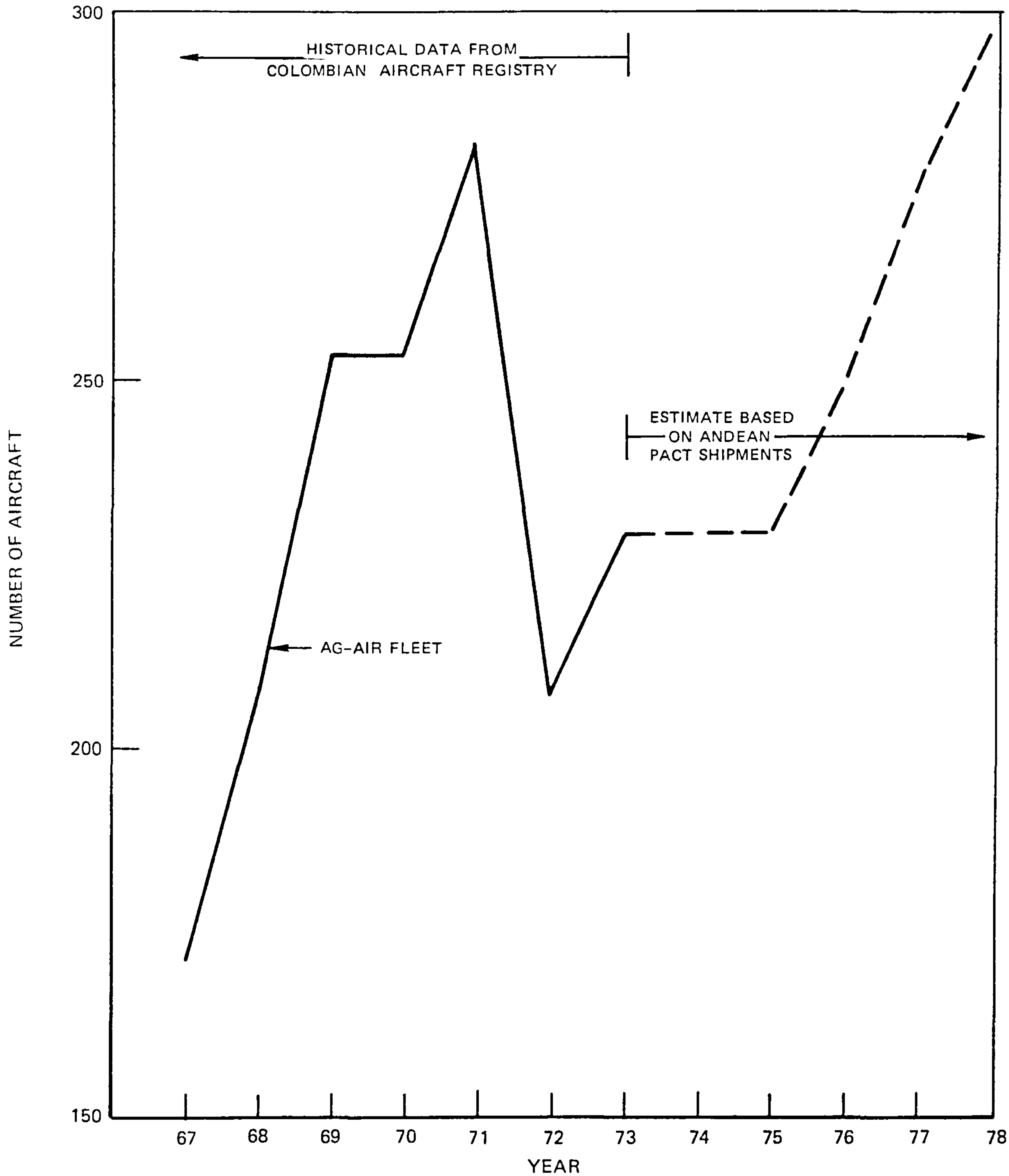
Because Colombian agriculture parallels that in the US in many respects, ag-airplane uses are similar. A comparison of ag-airplane utilization between Colombia and the US (Fig. 70) indicates that the Colombian fleet has been utilized about as intensively as the US fleet. However, these data do not indicate the <u>efficiency</u> of aircraft utilization in the two countries. The judgement of informed sources is that ag-airplanes are used more efficiently in the US. Therefore, more material can be deposited on target per aircraft hour by airplanes in the US fleet than by Colombian airplanes.

Aerial treatments by Colombian crop are depicted in Fig. 71. As in the US, cotton is the crop on which most aerial applications are concentrated. Therefore cotton applications have been examined in detail in the case study. Various grains and bananas are the other major crops treated by air in Colombia. A comparison of the relative distribution of ag-air activity by crop in the US and Colombia appears in Fig. 72. Although cotton is the single largest crop treated by air in both countries, cotton treatment has dominated ag-air activity in Colombia, primarily because of multiple insecticide treatments of cotton fields well in excess of US practice. Between cotton and rice, over 80 percent of Colombian treatment area is accounted for; in the US, these two crops account for less than the 40 percent of the total.

An interesting comparison of US and Colombian ag-air activity is presented in Fig. 73. The measure employed in this chart is the ratio of aerial treatment area to total area harvested for each of the major ag-air crops. The heights of the bars indicate the intensiveness of aerial applications. A bar extending above 1.0 signifies that, on the average, the harvested crop area is treated at least once by airplane.

FIG 68

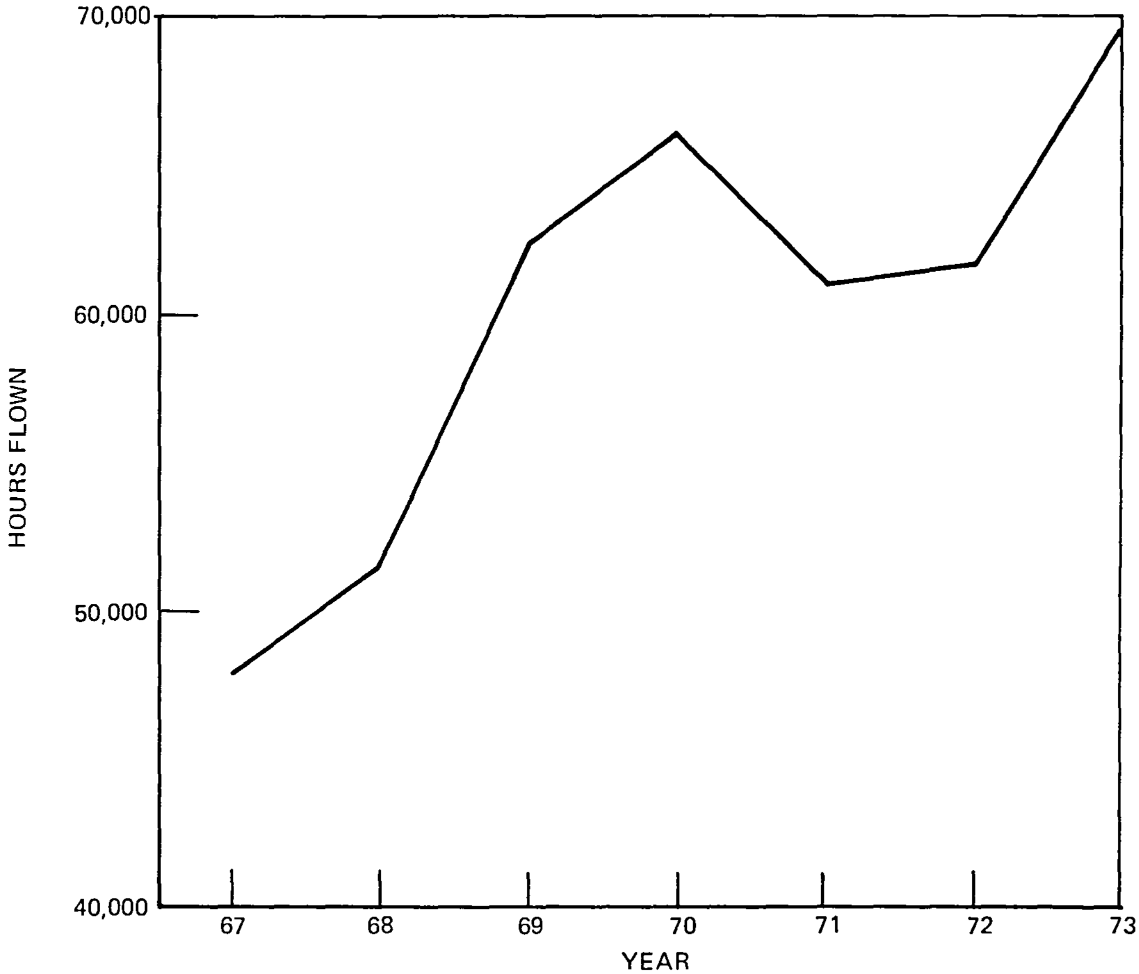
SIZE OF AGRICULTURAL AIRPLANE FLEET IN COLOMBIA



78-08-41-6

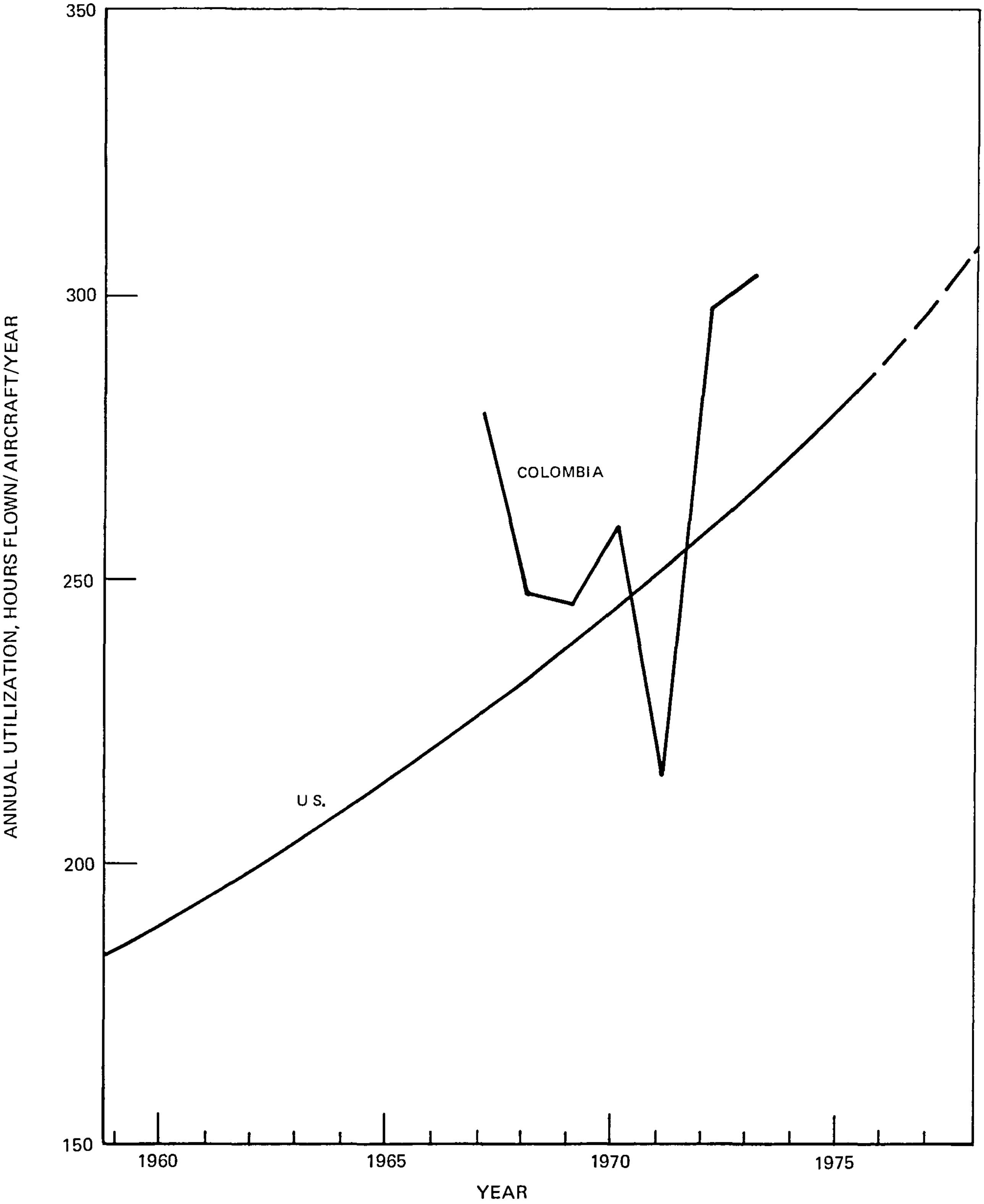
FIG. 69

HOURS FLOWN BY AGRICULTURE AIRPLANES IN COLOMBIA



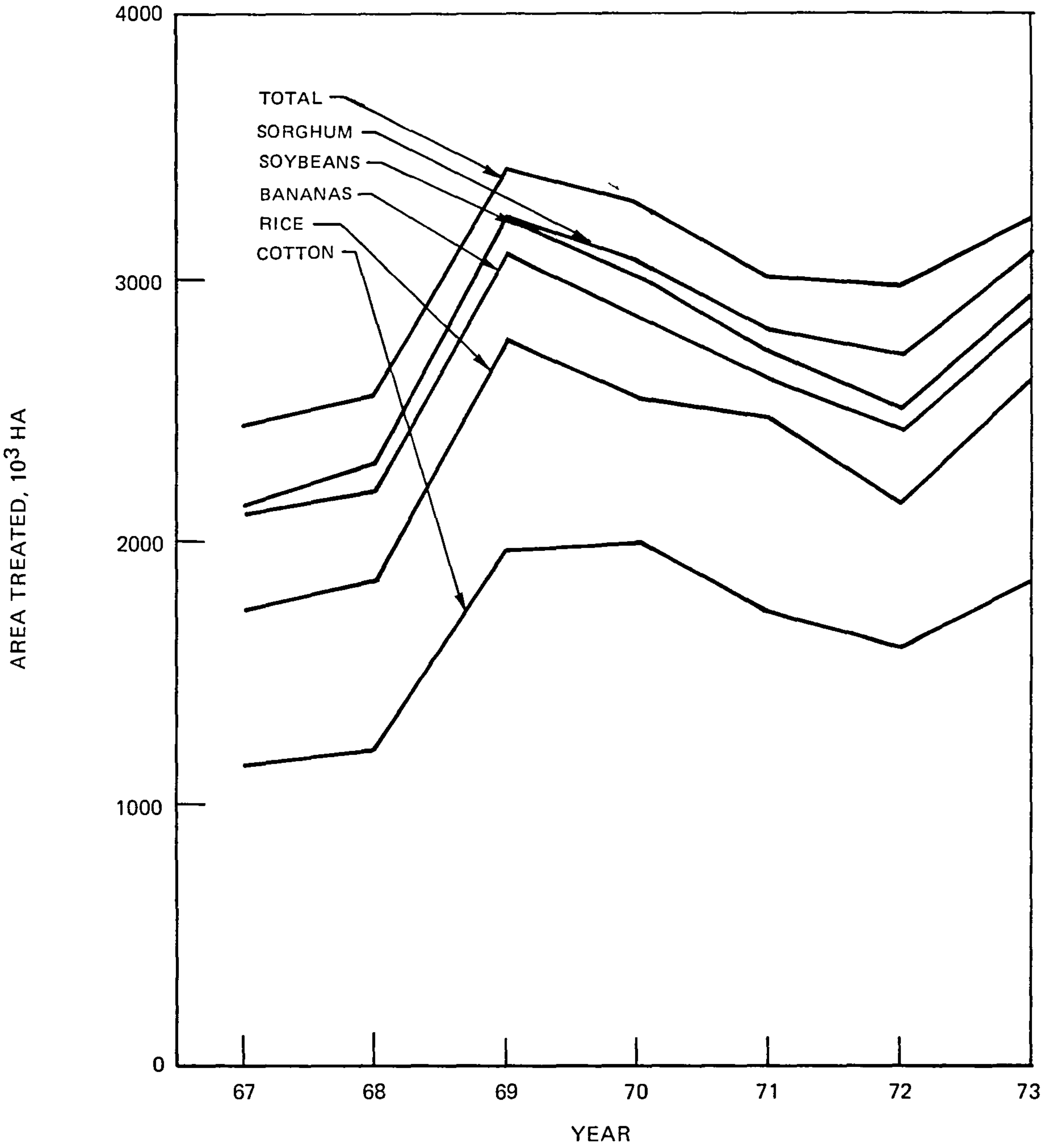
78–08–41–5

COMPARISON OF U.S. AND COLOMBIAN AG AIRCRAFT UTILIZATION



78–08–41–3

AREA TREATED BY AERIAL APPLICATION IN COLOMBIAN AGRICULTURE

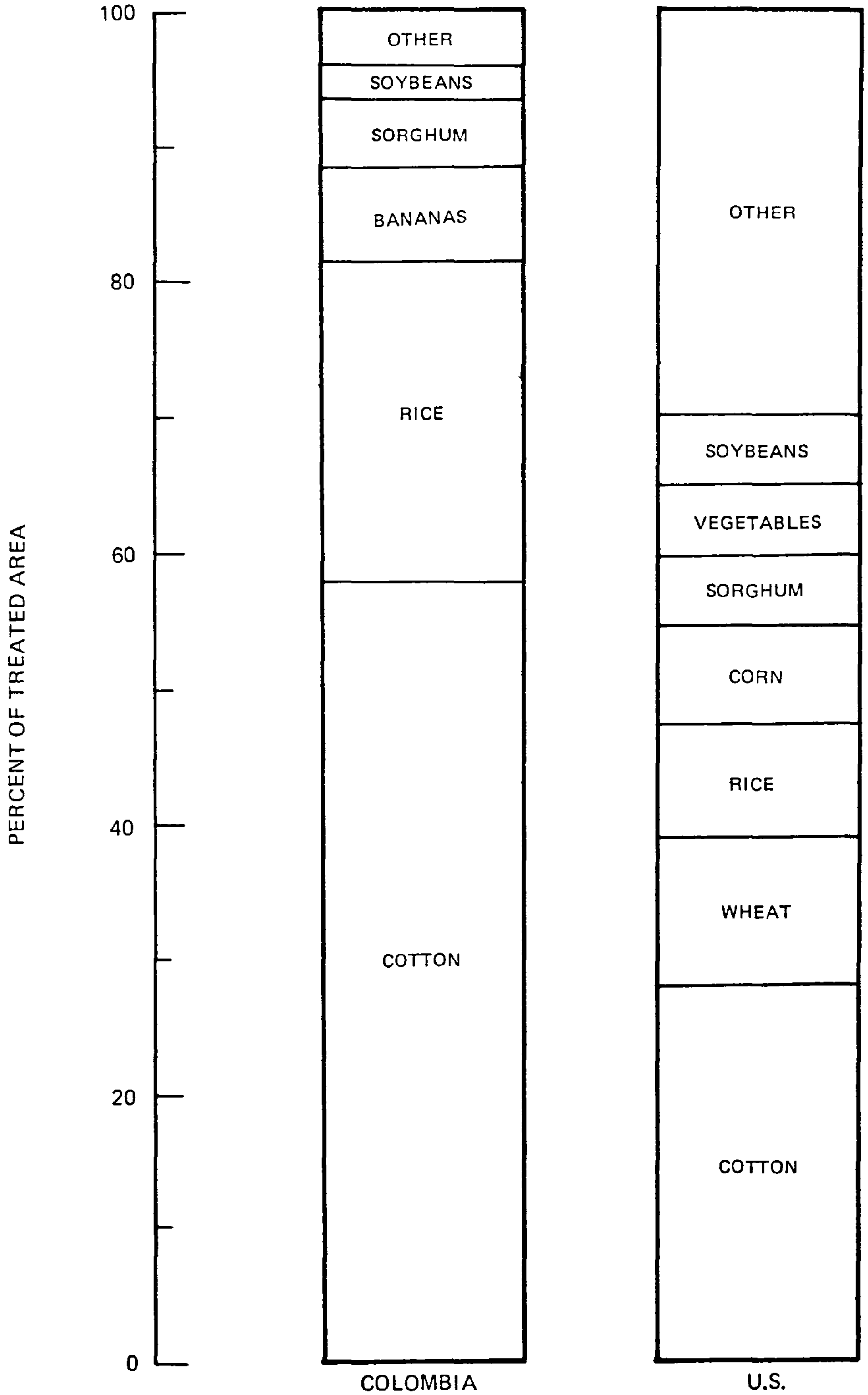


78–08–41–4

FIG 72

PERCENTAGE BREAKDOWN OF AREA TREATED BY AG AIRCRAFT

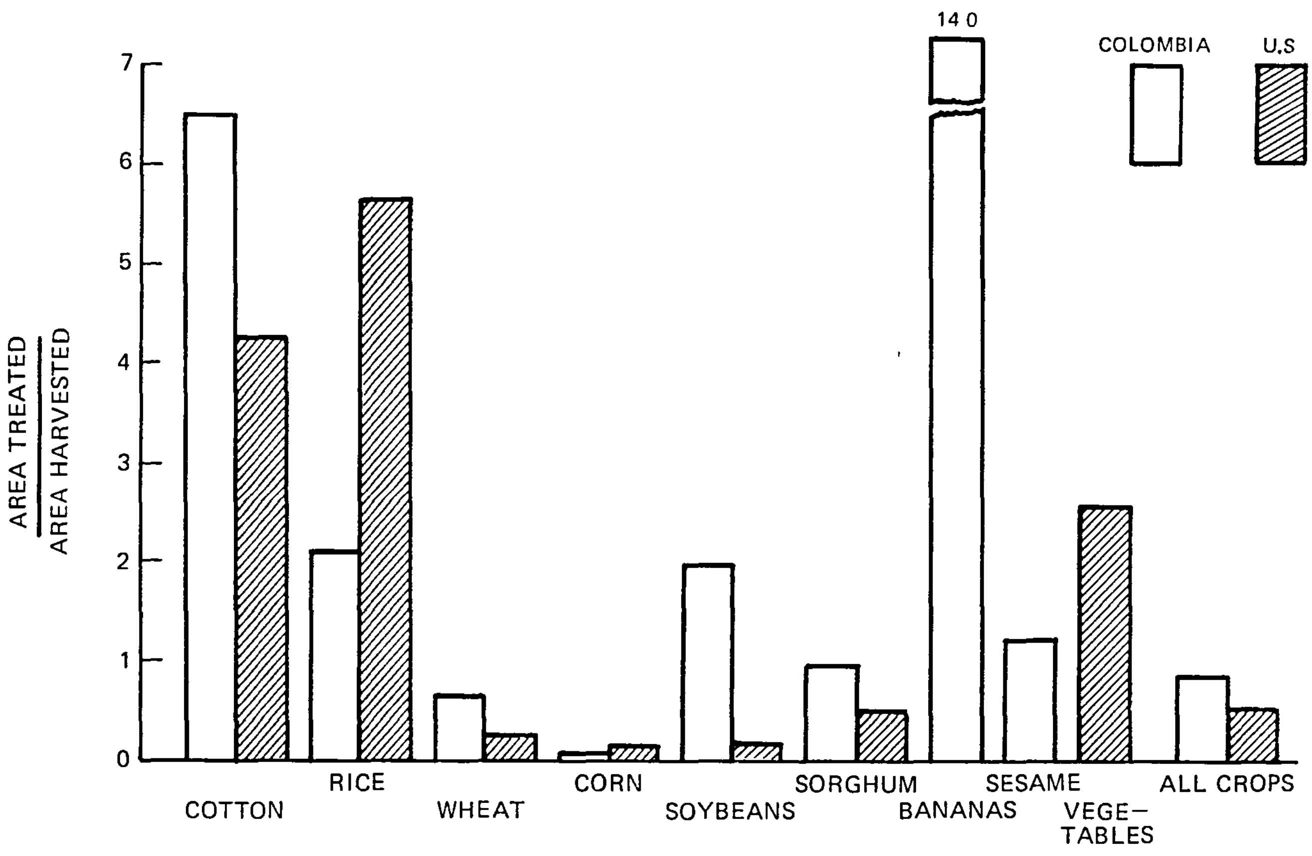
COLOMBIA AND U S



78–08–41–2

RELATIVE COMPARISON OF AERIAL TREATMENT FOR MAJOR CORPS

COLOMBIA VS. U.S



78–08–41–1

It is apparent from Fig. 73 that the intensity of treatment is greater for cotton in both countries, but much more so in Colombia than in the US. Conversely, US treatment of rice is significantly greater than Colombia's, which is not surprising, since a significant fraction of Colombian rice area is probably devoted to small farms, many of the subsistence type, which do not receive treatment. On larger farms, where rice is grown as a commercial crop for domestic consumption or export, ag-air practice is probably close to that of the US.

The basic grains--wheat, corn, sorghum--receive considerably less aerial application, as is also true of soybeans. These four crops account for a dominant share of US harvested area (66 percent), but a considerably smaller share in Colombia (23 percent). For all but corn, another common subsistence farm staple, Colombia's aerial treatment is more intensive than that of the US.

The remaining three crop categories in Fig. 73 are those for which no comparison can be made because one of the countries has no significant area harvested or treated by air. Nevertheless, these are important crops from the standpoint of aerial applications, particularly bananas in Colombia, and vegetables in the US. The ratio of 14 units of area treated per unit of banana area harvested is by far the most intense example on the diagram. Finally, aggregating all crops, it can be seen that Colombia actually uses aerial treatment more intensively than the US, although not necessarily as efficiently, as noted earlier.

Colombian Ag-Aircraft Manufacturing

The Colombian agricultural aviation industry has been growing very fast in the last ten years. Numerous general aviation aircraft models, including ag-aircraft, are assembled by Piper and Cessna licensees. Aircraft are provided for all Andean Pact nations; therefore many of these aircraft are for export. Interest has also been expressed by Embraer, of Brazil, to assemble their aircraft in Colombia. Importation of aircraft is prohibitively expensive because of the duty levied in order to support Colombia's own industry. Most airplanes in use, therefore, are Pipers and Cessnas assembled under license in Colombia, near Bogotá. There are about 280 ag-aircraft presently registered in the Civil Aviation Department.

In 1978, 27 Pipers were assembled, including the PA-36-300 and -375 models of the Pawnee Brave using Lycoming engines. The same number of airplanes is scheduled for production in 1979*. Unlike Cessna, all of the

*The Piper assembly plant is operated by Aero Industrial Colombiana S. A., and the Cessna plant by Urdaneta y Galvez Ltda. The firm of Aero-Mercantil Leaver & Cia. S.C.A. serves as sales agent.

1978 Piper production was delivered to the operators that year. Over 90 percent of the parts are imported, but there is an increasing integration with the Colombian industry, as required by the Government. For example, the welding of the main structure of the Pawnee Brave is now being done by an outside contractor on the premises. Each year additional primary manufacturing tasks must be adopted to assure continued growth of domestic manufacturing capability.

The same year, Cessna had manufactured 48 airplanes in Colombia for sale in Colombia and the Andean Pact countries, compared to 27 for Piper. Some modifications to aircraft have been done, such as softer landing gear and oversize tires for rough field capability. A new regulation will soon require all ag-aircraft to have communications equipment. Many of the parts used, such as fiberglass sections, are from local sources.

Structure and Problems of the Aerial Application Industry

Observations regarding the nature of the aerial application industry in Colombia and the problems it will face in the future are based on a visit made in early November 1978. The principal contact was Dr. Luis Fernando Gutierrez T. who is president of AVIAGRICOLA, the national association of aerial applicators. Other contacts made are listed in the Appendix. Although AVIAGRICOLA does not include all operators in its membership, it includes all the large operators and many of the small ones. Thus, its members represent the majority of aerial application work done.

The aerial application industry is very fragmented and consists mostly of small operators with one or more airplanes. There are currently 42 registered air applicators in Colombia and a fleet of about 280 airplanes. Official statistics concerning the number of operators and hours flown greatly underestimate the use of aircraft. Many aircraft are used by unregistered "fly-by-night" operators who avoid income declaration and legal restrictions. The maximum allowable monthly flying time per pilot of 90 hrs is often exceeded by operators in times of high demand, thereby introducing inefficiency of application because of poor meteorological conditions and insufficient attention to achieving good distribution. Although air application is done by specialized firms rather than by the growers themselves, large farmers often have ag-air subsidiaries. Competition is fierce among ag-operators. In cases where zones of operation are defined, it is difficult to control the operations of encroaching applicators, particularly "pirate" operators*. Lack of responsibility between farmers and illegitimate operators is a frequent problem. If crops are poor, the farmer may neglect to pay for services, and when demand for services is high, operators will seek out the best "accounts", while ignoring the small farmers. The present number of operators is excessive according to informed judgement*. An

*From conversation with Dr. Luis Fernando Gutierrez T.

industry consisting of perhaps ten large companies might result in a healthier competitive situation.

The problem of aerial spraying concerns, therefore, not only the airplanes themselves, but also the productivity of the airplanes and their effective utilization. Prior assistance from the United States in the form of technical expertise has come from Dr. Yates and a University of California AID group. They visited the Cauca and Tolima regions, offering many suggestions for improvements in technology and operations, and also ran training programs for pilots and operators.

The following table includes some statistics concerning air application in Colombia:

	No. of Companies	No. of Airplanes	No. of Runways	Ha Treated (10^6)	Value 10^6 pesos
1972	28	207	211	3.0	190
1973	33	229	236	3.2	225
1975	37	275	300	3.7	295
1978	40+	280+	-	5.0+	-

The data shown for area and value are tenuous estimates due to reporting problems and lack of sufficient knowledge of the operations. The number of airplanes is expected to grow at a much smaller rate in the future due to increases in their productivity. The large number of applications in recent years has been due not only to pest infestation, but also to poor timing of applications and poor practices. For example, in periods of high demand, sprayers have been known to operate up to 14 hours per day, even though the most effective spraying periods are 7-11 A.M. and 4-6 P.M. Also, there have been cases of improper mixing of incompatible chemicals in order to economize spraying costs. Emphasis is therefore being placed on more education of the grower and sprayer, rather than on more spraying.

Very little government support is given to the ag-air operators and very little interest is shown. Although long-term loans are available for tractors, trucks, and other farm equipment, airplanes must be bought by equity capital. The exchange rate is presently about 40 pesos/US$, subject to increases in cost due to further devaluation. Ag-operators are responsible for construction of their own airports and 90 percent of the operations are from private airports. Even though the importation of aviation parts is subject to preferential treatment, parts are expensive and often difficult to obtain. Their high cost precludes large inventories, while importation is very time-consuming. These problems are typical of the developing-country environment which is characterized by lack of good infrastructure.

The following table gives a breakdown of typical operating costs for an aerial applicator in Colombia*:

	% of Operating Cost
Airplane	9.22
Fuel	7.87
Aircraft Insurance	9.03
Other Insurance	1.29
Pilot	18.89
Administrative	12.71
Runway	3.04
Interest	16.68
Accessories	1.38
Legal Cost & Acctg.	0.92
Income Tax	0.71
Social Sec. & Fringe Benefits	5.72
Transportation & Other	1.38
Other	2.76

The operating cost has been about 100 pesos/hectare in the most recent year but is rapidly increasing, particularly in the fuel component.

In order to operate legally, an air applicator must obtain licenses or permits from the Instituto Colombiano Agropecuario (ICA), the Departamento Administrativo de Aeronautica Civil (DAAC), the Ministry of Public Health, and two permits from the Commerce Department. These complexities encourage "pirate" operators which the government has difficulty in controlling. One step in that direction has been recently taken, however. The ICA is transferring its responsibility of licensing aerial application firms to a new department in the DAAC, which has been formed to deal specifically with agricultural aircraft. This change should result in closer cooperation between aircraft registration and company licensing, as well as more interest in ag-aviation as an industry. The appropriate chemical application is prescribed by an agronomist from the ICA, while the grower supplies the product to the air applicator. The quality of agronomists is considered high, though other problems of education and surplus unskilled labor remain. Ag-pilots are generally acknowledged to be sufficiently trained -- there are 5 schools for agricultural flying -- and recently there has been a surplus of pilots. The accident rate has been high but is improving. However, maintenance of aircraft is a constant problem due to lack of qualified technicians, poor quality of facilities, and difficulties in parts supply.

---

*From Dr. Luis Fernando Gutierrez T.

In general, the ICA prefers a minimum of regulations in keeping with a free-enterprise system. Although a zone system of operations is frequently used, open competition is advocated. Even though problems exist with chemical contamination (even deliberate dilution) along the distribution chain, it is not likely that applicators will be responsible for purchases of chemicals in the future. The policy of the ICA is to minimize the need for aerial spraying whenever possible. Biological controls in early stages of growth are advocated. Ground spraying is suggested when possible, particularly when selective spot spraying in early stages of infestation can be used. This policy is expected to allow for better monitoring and inspection of crops during their growth.

About 60 percent of the aerial application of chemicals is for cotton, resulting in a strong dependency by ag-operators on the crop. Much of the growth of ag-aviation has been attributed to increases in the area planted for cotton. The last two years have been poor ones for cotton, particularly 1977, because of unusually severe insect infestation and bad weather. In their efforts to control the pests, farmers made extensive use of aerial spraying. Typically, 25 to 30 applications were made during the growing season. Demand for aircraft was high, resulting in long hours of use with little time for maintenance. Unfortunately, for a number of reasons, little success was met and cotton production decreased markedly. In addition, cotton prices on the world market fell and the farmers took great financial losses, despite some Government subsidy. In response to that situation, areas planted for cotton in 1978 were reduced by about 1/3 and farmers resorted to more biological control of pests. The problems of the past year did not recur, although cotton exports have been curtailed and unemployment has increased. For the aerial applicators, the result was that 1/3 of the fleet remained on the ground. Operators who depend mostly on cotton are in financial difficulty, although the outlook is brighter for the future.

An important problem encountered by operators is the lack of effectiveness of their spraying. Operators get blamed for their failure to control pests, and they in turn blame the quality of the chemicals. Very frequently, the cause is a combination of poor timing of application and the resistance developed by insects. Chemical contamination is also frequently responsible, but this is usually not due to poor quality control by the manufacturer, as is often claimed. Formulations are mixed by the Colombian manufacturers from imported raw materials with a tolerance of 15 percent, as compared to about 10 percent in the US. Contamination frequently occurs along the distribution chain, with pilferage by substitution of inert products for high-value active ingredients. There is also a large market for fraudulent products sold at competitive prices, with the blame for their ineffectiveness passed on to the legitimate manufacturers.

A number of US companies (such as Shell and Dow) are involved in the sale and distribution of chemicals. The only agricultural chemicals produced by Shell in Colombia are insecticides, of which 85 percent are used on cotton. Dow does not distribute insecticides in Colombia, although they are planning to do so in the future*. Herbicides for pasture (phenoxys) are applied by ground equipment, since most pastures are located too close to susceptible crops. They are also applied to other crops by ground means, with some air application to sorghum.

There are several policies initiated by the ICA recently, to improve the effectiveness of pest control. The use of ULV (ultra-low volume) spraying is being curtailed for reasons of inadequate supervision. This practice requires careful preparation of chemicals, precise calibration of equipment, and good spraying techniques. The consequences of improper use are severe in terms of environmental damage, crop losses, and hazards to the applicator and his equipment. In February 1978, an application rate of at least 7 gal/ha was suggested, and the use of ULV is declining. The ICA also advocates the use of biological controls whenever possible**. By using insect populations which feed on the insects causing crop damage, and maintaining a delicate balance of predator and prey, such methods are effective in early stages of infestation and eliminate the need for chemical application at the beginning of the season. The implications of these trends in Colombia are significant because they indicate an awareness of ecological factors which is closely coupled to US developments. Direct contacts by officials of the Colombian government and private individuals with their counterparts in the US result in rapid transfer of US initiatives, particularly in the regulatory area. For this reason, regulation-driven changes in the structure of the US ag-air industry are likely to be adopted quickly by Colombia and other LDCs, even though some economic penalties may be suffered in the short term. The example of de-emphasizing ULV spraying because of inadequate knowledge and control by operators is a case in point.

Although it may seem that sales for chemical companies would be reduced by competition from biological controls, the reverse is actually true in the long run. Widespread use of chemicals results in insect immunity, which leads to the need for development of new chemicals. This development is extremely expensive for the chemical companies. A more reasonable approach is to use biological controls, supplemented by spot spraying by ground means and, finally, by aerial spraying in later stages of infestation. In the long run, this policy provides for better pest control and eliminates the great expense of developing new chemicals. For aerial applicators, it results in less erratic business, more predictable aircraft needs, and more confidence and success in their methods. New pyrethroid insecticides (such as "Belmark" marketed by Shell in Colombia) have been found compatible with biological controls since they do not kill trichograma, used in biological control. An effective means of control for cotton using the technique described above should require, at most, 12 aerial applications per season--an average of 6-8

*From conversation with Mr. Manual Castro of Dow Chemical.

**From conversation with Dr. Elkim Bustamante of ICA.

applications of pyrethroids and 4 applications of other products. This trend is expected to continue into the foreseeable future.

Besides the widespread aerial application of insecticides (60 percent of them on cotton, 25 percent on rice), airplanes are also used for urea and foliar fertilizers. Fertilization of cotton, however, is usually done by ground equipment at the beginning of the season. Helicopters are used almost exclusively for bananas for fungus control. Use of fungicides in rice will be reduced by future development of resistant rice strains. Present opinion is that fertilizer should not be mixed with other chemicals during application but much research remains to be done in this area.

A major constraint against expansion of agricultural production and yields is the lack of irrigation for crops other than rice. Although the climate could allow double cropping and higher yields, the necessary investment cannot be justified at this point. So, the future of ag-air certainly depends on the possibility for irrigation development. The present situation is one of guarded optimism. In the emerging agriculture of the Llanos, for example, there has been much caution with use of pesticides in 1978. A shift toward more integrated pest management has occurred with a reduction to about 2 or 3 aerial applications. At current prices of cotton, about 5 or 6 aerial applications are possible in order not to exceed the break-even point for profit, after last year's loss of US $100M. Research into long-term effects (residue analysis) will affect the spraying of crops, which may require very close monitoring of the last spray. This makes it necessary to exercise great care in spraying perennial crops, such as the African oil palm, where residues may accumulate from year to year.

Another factor affecting ag-aviation has been land reform, which has spread land ownership and reduced the average size of land holdings. Although there were good results in 1961-68, land reform slowed in the 1970s and was less successful. The trend toward smaller holdings is expected to stabilize, to the benefit of the ag-aviation industry. Use of ag-air for small holdings, even on a shared basis, is unlikely due to lack of cooperation among adjacent farmers. Because field size is such an important determinant of aircraft use, a quantitative analysis of field size was made for the Colombian environment, and is described in the Appendix. In discussions with government representatives, the opinion was expressed that, in general, application of insecticides on fields smaller than 25 ha should be done by ground machinery, or backpacks.

In the future, no great change is seen in the overall structure of the industry. Chemical companies will probably continue to sell to distributors (companies, federations, cooperatives and in certain cases, large farmers) who mix the chemicals. This situation is different from some LDCs, such as in Africa, where the governments organize small, poor farmers and hire large organizations to do application, with the condition that they guarantee a minimum yield. Since it is not possible to maintain sufficient control over agricultural inputs in Colombia, such a practice is not possible. It is also inconsistent with the government's policy of small-scale, free enterprise.

For individual crops, it is expected that the production of grains will increase, although the aerial applications required will remain small unless a significant shift to aerial fertilization occurs. Soybeans will become increasingly important, but they are not susceptible to excessive insect infestation. Rice will experience a slow but steady growth with continually increasing irrigation. Sorghum and maize will increase moderately in proportion to population. As land values increase, pasture will become increasingly important, with a large expansion on the north coast in 5 or 10 years, followed by the Llanos. There could be a need for fertilization and seeding by air once this development takes place because the Llanos is a vast area in which large fields inaccessible to ground equipment will predominate, as in the USSR.

Some improvements in air application technology are necessary. Closed systems for mixing of chemicals are clearly desirable, as well as some provisions for mixing of chemicals within the airplane hopper. Most aircraft have some recycling systems; ones that do not should be so equipped. Flowmeters to control volume of application are very useful, particularly for ULV, and are used in Egypt and the Sudan.

Among the technological improvements for which need was expressed was the requirement for more power, even though a larger opposed eight-cylinder engine is now being installed in the Piper airplanes. Although a turbine engine would solve this need, uncertainty of maintenance skills in Colombia and high cost are formidable obstacles. These and other suggestions for technological improvements are discussed further on.

For the future, therefore, the outlook for ag-aircraft will be strongly linked to the future of cotton production. The land reform of the past years has spread land ownership and generally reduced the size of holdings. Now the government is placing emphasis on increasing the productivity of the land through inputs of technology. Investment in irrigation is still lacking and the utilization of the land is still poor, but gradual improvement should be forthcoming.

Aerial Application for Cotton

Cotton, the predominant ag-air crop, presents an interesting case of the many factors affecting aircraft use. Because it is a valuable export crop, much attention is given to control of disease and insect infestations, which would greatly reduce yields if left unchecked. As mentioned before, great losses suffered by the cotton crop of 1978 had a large impact on the growers and aerial applicators. The Colombian ag-air industry is, therefore, greatly dependent on prospering cotton agriculture, and this dependence is likely to continue.

In the Costa (North) region, the cotton growing season begins in July and August and continues through December or January. In the interior (Tolima, Huila, Valle, Cundinamarca, Meta) it begins in January and ends in August. Cotton production is growing particularly fast in Meta, the flatlands east of the Bogotá area. Generally speaking, cotton fields are larger in the coastal region than in the interior and more cotton is grown there than elsewhere -- about 80 percent of the cotton production is in the North, and about 20 percent is in the interior.

Current cotton yields are about 1500 kg/ha of seed cotton, or about 1/3 of that for lint cotton, compared with yields of over 3000 kg/ha achieved in South Africa and on experimental farms in Colombia. It is expected that yields should reach 2000 kg/ha with proper conditions. New varieties will be required which will adapt to irrigation, once it is developed. Pyrethroid insecticides now coming into use can increase yield as well as substitute for organo-phosphates, to which insects have developed immunity in the last 3 or 4 years.

The attack of heliothis of 1977 was controlled by organo-phosphates. The crisis developed when the chemical companies were caught unprepared and did not have the necessary lead-time to import the proper chemicals for control. Since the companies cannot keep large inventories of the chemicals (valued up to 1000 US $/gallon!), farmers applied the existing products in excessive amounts. Insects developed an immunity to these chemicals, and the situation was further aggravated by pressure on the aerial operators from the farmers and poor timing of applications.

The situation in 1978 improved greatly. Heliothis had not appeared in nearly the same magnitude as in 1977. Because farmers did not pull up stalks of cotton after last year's harvest due to heavy losses, other insects (pink boll worm and boll weevil) appeared but were controlled adequately. An important factor in this success has been the reduction of the area planted. One reason why cotton area was reduced in 1978 was that the Government and the bankers failed to give credit to farmers. The result of this action has had a very positive impact, aside from raising the price of cotton. Farmers have been keeping a closer watch on their fields, and applicators have been much more careful in their spraying techniques. More judicious use of chemicals, aided by biological controls, has improved the situation markedly. For the aerial operators, particularly those who depend on cotton alone, financial losses unfortunatley continue due to underutilization of their airplanes.

Cotton production is closely associated with the growers' organizations. Unlike other crops, cotton growers get credit for aerial spraying from the organizations, which also distribute chemicals at a discounted price. The largest of these associations is the Federacion Nacional de Algodoneros, which includes the majority of cotton growers. It closely monitors US production because of the US influence in setting international price. The association is concerned with rising costs of production in Colombia (Ref. 40). If cotton is not profitable in the future, it would be necessary to switch to other crops such as soybeans, rice, and sorghum. The uncertainties of crop production and fluctuating world prices make it important to examine the relationships among the variables which affect cost.

To illustrate, data provided by the Cotton Growers' Federation are given in Table 21 (Ref. 41). A large variation in costs and yields from region to region and from year to year is apparent. Note that pest control is a very significant portion of the total cost of cotton production -- up to 40 percent. Application cost is a significant part (23 percent to 39 percent), and the ratio of material cost to application cost is lower than that, shown previously in Table 18 (3-4 compared to 8-22). However, the application cost given here includes both surface and aerial application, even though 60 percent of application is done by air. The cost per application given in Table 21 is higher than that predicted previously, but this can be accounted for by differences in the airplanes used and their utilization. Also, it is not known exactly what other costs may be included in the application cost category (such as airport and warehouse construction, transportation costs, etc.). Nevertheless, the costs are useful for the purpose of comparison with other production costs to assess the feasibility of improvements.

Ignoring, for the moment, the Tolima data for 1975, the results of the 1977-78 crisis can be clearly seen in Table 21. The number of applications increased sharply, increasing total pest control costs even though material costs stayed relatively constant*. Yields, on the other hand, did not rise but dropped sharply instead, resulting in great losses to the growers. Efficiency of application dropped, as seen by the higher cost of application relative to materials. It is interesting to see that, in 1975, the same strategy of more applications was followed in Tolima and returned a high yield and a net profit for the growers. The next year, 1976, chemical prices rose somewhat, and the number of applications was reduced, but yield remained high, resulting in very high profits.

Although price and yield contribute directly to profits, the importance of reducing pest control cost is that it tends to be a marginal cost which affects profits. On the other hand, the cost of pest control must be weighed against the likely improvement in yield. This decision is made on the basis of expected price of the crop each year, which varies widely and results in wildly fluctuating profits. Figure 74 illustrates these relationships, where the slope of the revenue line indicates the price of cotton ($/kg). Profit (or loss) is the difference between the cost and revenue lines. The dotted lines indicate necessary improvements in yield and reductions in cost to produce equivalent increases in profit (indicated by the heavy lines).

The equivalent yield increases corresponding to a hypothetical 10 percent reduction in fixed cost are given in Table 21. A more meaningful

*Note that there were significant regional differences in materials cost per application. For Tolima, cost per application declined slightly, indicating that chemical prices did not rise.

TABLE 21

COSTS OF
COTTON PRODUCTION IN COLOMBIA

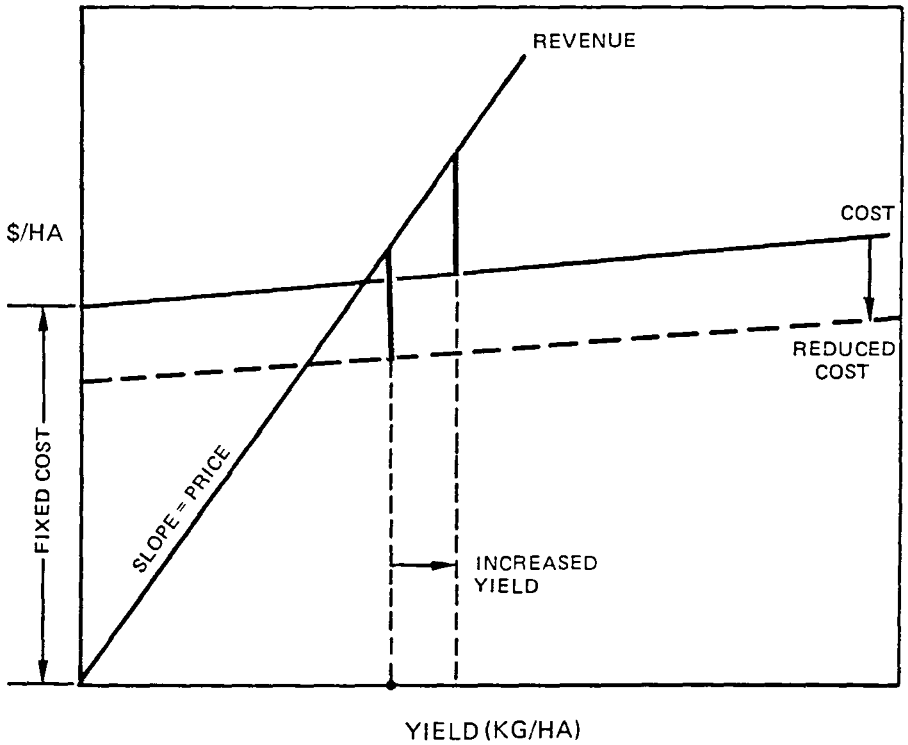
All costs(1) in US $/ha, unless indicated

	1975 Tolimas	1976 Tolimas	1977 Tolimas	1975 Valle del Cauca	1977-78 Costa-Meta
Total cost of production	698	709	942	698	1117
Variable Cost(2)	154	174	196	147	191
Fixed Cost	544	535	746	552	925
Cost of pest control	233	197	298	148	439
% of total cost	33%	28%	32%	21%	39%
Value of materials	187	149	206	106	283
Cost of application	44	41	77	39	111
Ratio of mat cost/app cost	4 25	3.63	2.68	2.72	2.55
Other costs	2	6	15	2	45
Yield, kg/ha	1850	1850	1200	1750	850
Application data					
No of applications	18	12	19	13	21.5
Cost per application	2 42	3 43	4 05	3 03	5 15
Material data					
Cost per application	10 39	12.42	10 84	8 15	13.16
Profits					
Price paid, $/kg	0 41	0 65	0 55	0 50	0 61
Revenue	762	1199	660	872	515
Profit	+65	+490	-282	+174	-593
Equivalent yield incr. corres. to 10% reduction in fixed cost	9%	5%	16%	8%	28%
Equivalent fixed cost reduction corr. to 10% increase in yield	11%	19%	6%	13%	4%

(1) Assuming the following approximate exchange rates for Colombian pesos to US dollars
1975 - 33
1976 - 35
1977 - 37

(2) Such as transportation, storage, etc

COST AND REVENUE RELATIONSHIPS



79–01–274–7

interpretation is to look at the equivalent cost reduction corresponding to a 10 percent increase in yield. That is, if yield can be increased by 10 percent through better aerial and/or chemical technology, the percent of fixed production cost in the last line of Table 21 can be saved. This is also equivalent to the maximum allowable increase in production cost if it results in a 10 percent increase in yield. If costs incurred to achieve these increased yields can be kept below these amounts, additional profits can be realized.

The actual improvement in yield which may be possible due to improved aerial application technology is difficult to quantify at this point. Only a crude sensitivity analysis can be made, keeping in mind that the application costs in Table 21 include surface as well as aerial applications. The following table shows the maximum allowable percentage of application cost increase for three improvements in yield, assuming the improvements in yield are a direct result of better, but higher-cost technology:

ALLOWABLE PERCENT INCREASE IN APPLICATION COST

Increase in Yield	1975 Tolima	1976 Tolima	1977 Tolima	1975 Valle del Cauca	1977-1978 Costa-Meta
1%	14	25	6	18	3
5%	68	124	29	92	17
10%	136	248	58	184	33

It is clear that considerable increases in application costs are acceptable in return for relatively small improvements in yield, particularly when profits are high. Since the initial cost of the aircraft is only a small part of the operating cost (about 9% in Colombia), an even larger increase in the cost of the airplane is justifiable if it can be demonstrated that the airplane will increase yields. It is more likely that yield increases would result from a combination of improved ag-aircraft, better chemicals, and more effective application techniques. Nonetheless, the leverage of such increases would be great. Thus, technological improvements may produce a very high return on investment. It is obvious that quantification of the attainable improvements in yield resulting from improved application technology and the associated costs is an important area of research. These costs may be higher or lower than existing technology, depending on the airplanes and the nature of the operations. It has been shown that an increase in cost for current operations may show net benefits if the technology improves yields. Further benefits may accrue if cost savings can result for other types of aerial applications, such as high-volume fertilizing. The next section examines these trade-offs for existing and future airplanes as they apply to Colombia.

Analysis of Ag-Aircraft for Cotton and Rice

This section contains, for the specific case of Colombia, a comparison of the candidate aircraft introduced earlier. The same assumptions were made regarding aircraft costs, utilization, and the method of operation. Because cotton and rice constitute the majority of aerial application work, the analysis was done for both of these crops. Based on the land distribution analysis for Colombia in the Appendix, an average field size of 40 ha was assumed for rice and 65 ha for cotton*.

Cost of application ($/ha) for rice is shown as a function of application rate in Fig. 75. The range of application rates for various applications on rice are shown, based on US experience (Ref. 10). Typical application rates used in the general operations analysis are indicated by the dotted lines. About half of the applications made on rice are in the low-volume range for which the Pawnee is the most appropriate of the existing aircraft. However, for high-volume applications characteristic of herbicides, fertilizers and seeds, the small aircraft is uneconomical. At the highest application rates, a large current-technology airplane like the Turbo Thrush offers considerable savings over the Pawnee and AgWagon, which are offset by only a small increase in cost for low-volume work. The Improved AgWagon appears to be an even better choice, but the Lockheed AGB-7-TB1 design (Ref. 32) is too large to compete in the low-volume case.

The comparison above assumes that the airplane loading is done at the edge of the field being sprayed. Depending on the size of the farm, fields may be located a considerable distance away from the loading point. If loading is done at the applicator's base, the ferry distance is determined by the operator's radius of operations. To illustrate the effects of longer ferry distance, which is more appropriate in LDCs than in the US because of the differences in accessibility, it was assumed that loading is done 10 km away from the field. Although 10 km is probably much longer than a typical ferrying distance, in Colombia, it is not an unreasonable distance from which to operate. Results in Fig. 76 show that, for higher application rates, costs increase very rapidly for small airplanes like the Pawnee because of its very small payload. The Lockheed design shows a clear superiority at high application rates as payload becomes the dominant factor. It is obvious that for future expansion of fertilizer work, it will be extremely important to locate loading points adjacent to the fields. If this is not possible, then a larger airplane is the appropriate choice because it offers significant advantages over existing models.

Similar curves were obtained for cotton, as shown in Figs. 77 and 78. Application rates for cotton are lower than for rice because of the frequent

*Note that, in the case study, it was possible to obtain different field size estimates for each crop, whereas for the world regions this level of detail was beyond the scope of the study.

RICE APPLICATION

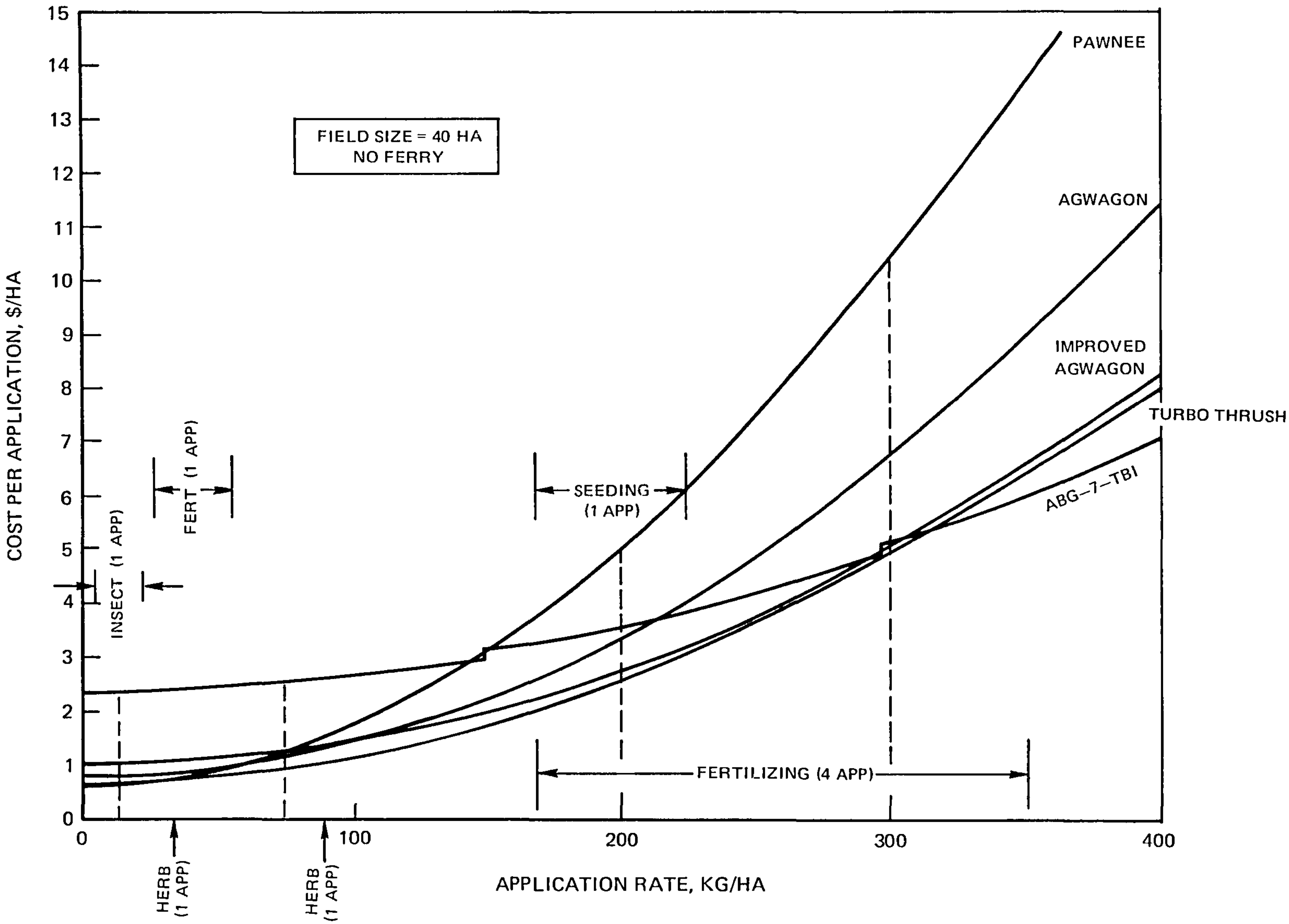


FIG 75

79–01–274–2

RICE APPLICATION

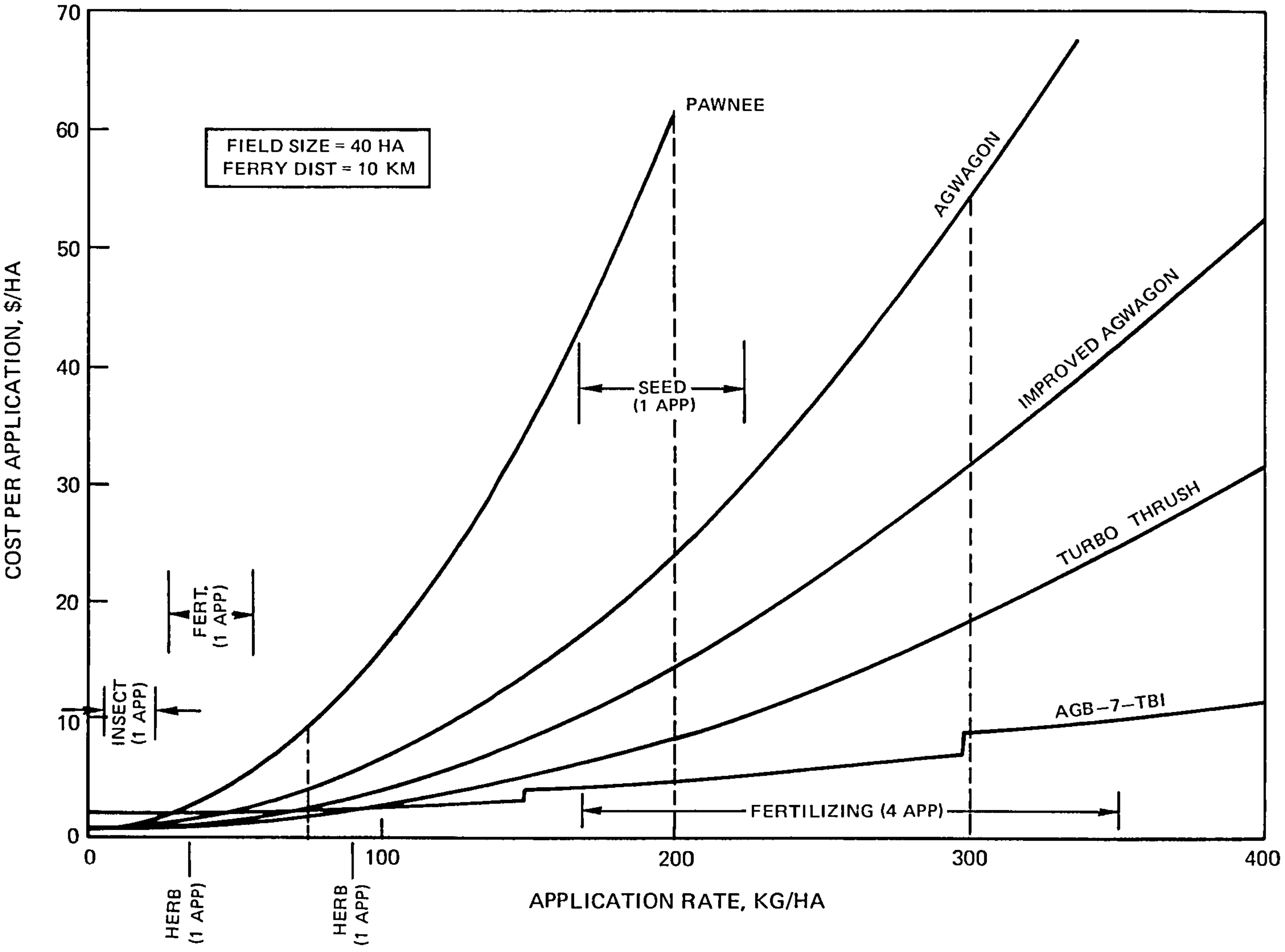
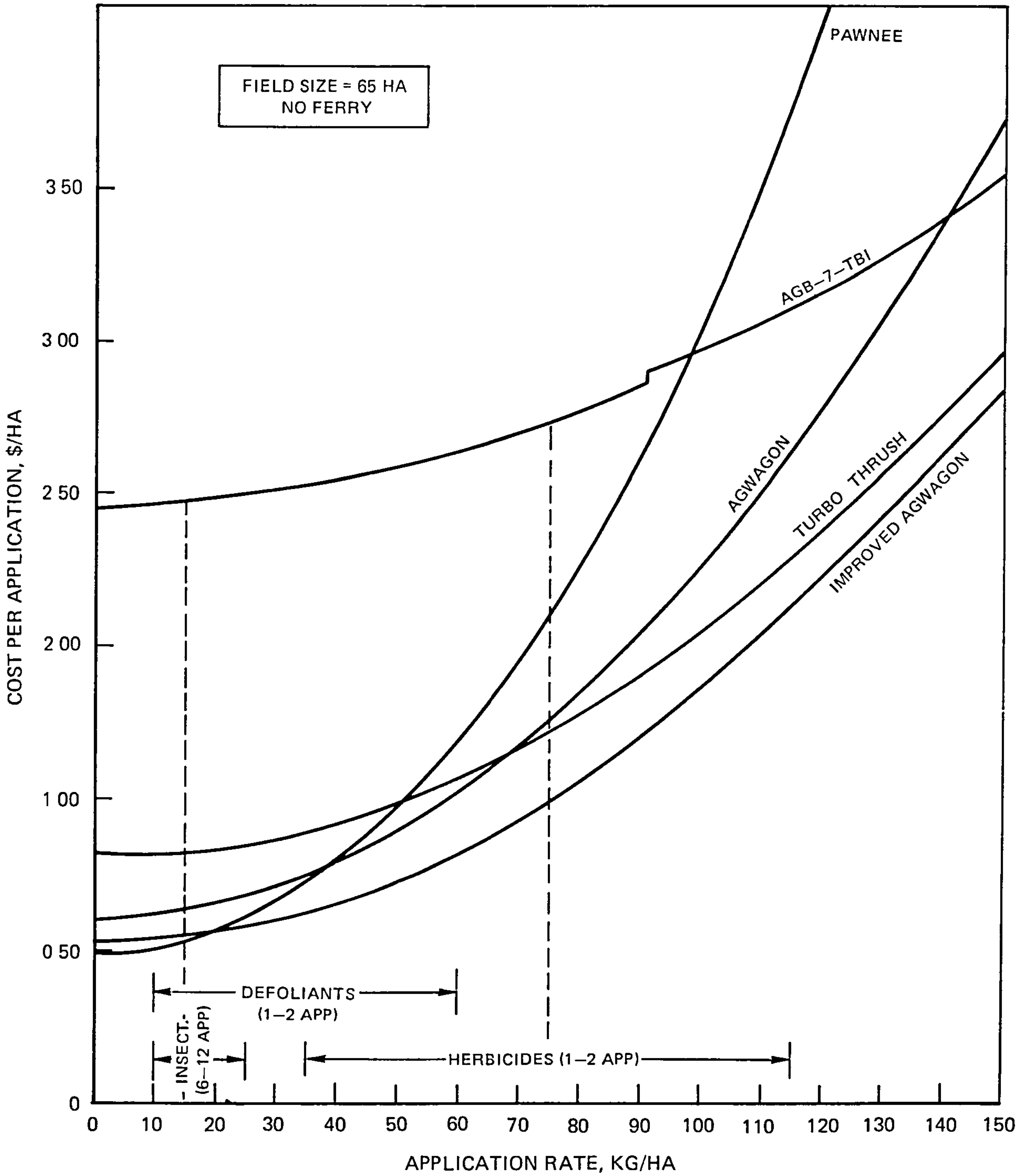


FIG 76

79–01–274–3

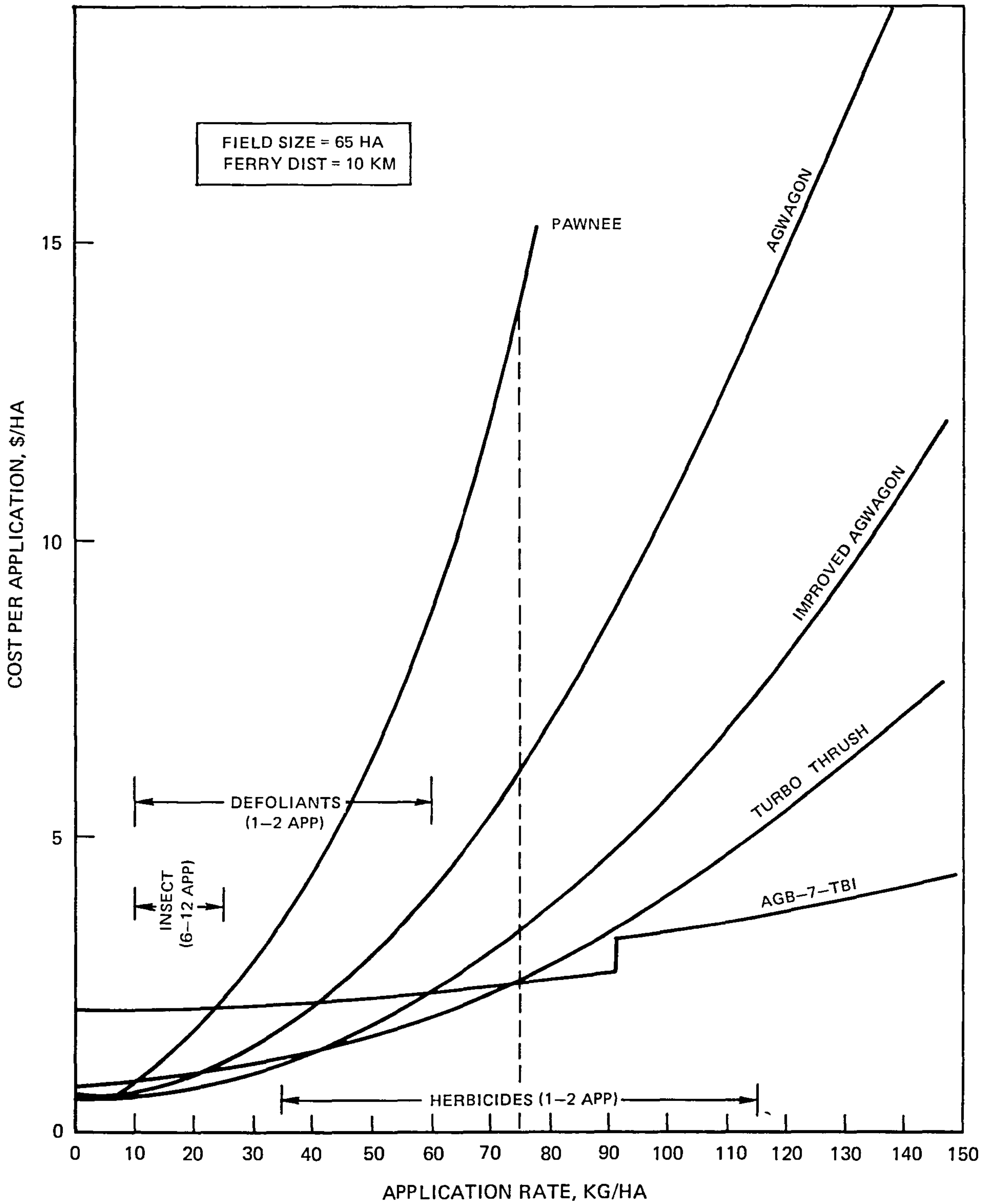
COTTON APPLICATION



79–01–274–4

FIG 78

COTTON APPLICATION



79–01–274–5

insecticide applications. Since smaller airplanes show a superiority for insecticide work, their use is indicated, although the Improved AgWagon, a medium-size airplane, is the best choice because of performance advantages gained at a relatively small increase in cost. The effect of increased ferrying is not as pronounced at these low application rates, but the Turbo Thrush still manages to emerge as a good competitor in Fig. 78.

In summary, it can be seen that changes in the airplane fleet and method of operation will be necessary if large-scale fertilization is to be done by air. For most of current applications, airplanes such as the Piper Pawnee are satisfactory. The improved version of the AgWagon appears to be a good alternative to current airplanes, but a very large future airplane would not show any advantages for the majority of the aerial application work done in Colombia, even for the high utilization (600 hr/yr) assumed in these calculations.

AG-AIRPLANE TECHNOLOGY

It was shown earlier in this report that US ag-aircraft are prevalent throughout the free world fleet and that export shipments continue to be an important part of the US manufacturers' sales. Therefore, it is clear that the US manufacturers have responded to the needs of the world market by producing airplanes that are competitive, in both their performance and their cost characteristics, with aircraft of foreign manufacture, and that they cover an appropriate range of sizes. The question of size has been adequately covered in previous sections, larger aircraft will be required in the future, but not in every regional market. Since the question of technology content has not been addressed thus far, the purpose of this section is to provide some guidance concerning the technology emphasis pertinent to foreign environments. In particular, the special needs of a typical LDC will be described as it compares with the developed-country environment. The section is divided into two parts, the first concerning quantitative comparisons of technology improvements, and the second concerning some specific items which emerged from the Colombian case study.

Developing Country Requirements

There are several areas in which technological improvements might be made in ag-airplanes. The list which follows enumerates the primary parameters for which improvements could be achieved by implementation of advanced technology, categorizes them according to primary technology areas, and indicates the performance impact each improvement would cause. The impacts relate directly to the productivity equation presented in the operations analysis.

Primary Technology Area	Parameter	Impact
Aerodynamics	Lift/Drag	Payload
	Stall Speed	Turn Time
	Field Speed	Field Time
	Ferry Speed	Load Time
Structure	Empty Weight	Payload
	Load Factor	Turn Time
Operations	Swath Width	Field Time
	Application Rate	Field and Turn Times
	Loading Rate	Load Time
Propulsion	Fuel Consumption	Payload
	Engine Power/Weight	Payload

In addition to the above, other improvements might be included under each of the primary technology areas.

Aerodynamics:	Handling qualities
Operations:	Materials distribution; Guidance; Maintenance and Reliability
Propulsion:	Noise, Emissions

These latter improvements are more difficult to evaluate quantitatively than those in the first group. Handling qualities are probably more important in the LDC case because of a somewhat lower pilot skill level. Maintenance and reliability problems are also likely to affect the LDC operator more than the developed-country operator because of the relative availability of technical skills and spare parts in developed countries. Uniformity of materials distribution is clearly an important technology area because it affects the efficiency of dispersed materials. As shown earlier, a small percentage reduction in material required in an aerial application is equivalent to a much larger decrease in aircraft-related costs. Improved guidance should be especially important because it promises the achievement of more even distribution of materials with minimum overlap between swaths. The resulting saving in materials should easily offset the required installation cost. Noise and emissions are not yet important in ag-air in most parts of the US, and are undoubtedly less important in LDCs than in developed countries.

A quantitative analysis of the parameters in the first list was performed for cases which represent uses in developing and developed countries. Two airplanes were considered -- the AgWagon and the Turbo Thrush -- and calculations were made for typical field sizes of 50 ha for LDCs and 150 ha for developed countries. A range of application rates (15, 75 and 200 kg/ha) was also considered in the comparison. The results are presented in Table 22 in the form of sensitivities of application cost (excluding materials) for small changes in each parameter. For example, a 10 percent increase in lift/drag reduces cost by 31.9 percent at an application rate of 15 kg/ha in developing countries. The sensitivities are based on the operating cost and productivity equations presented earlier. Partial derivatives were taken with respect to each parameter to determine the effect on application cost.

A ranking of these results can be obtained by considering the relative occurrence of each application rate in Table 22. Because the percentage of insecticides applied at ULV rates is unknown, the analysis was performed in two parts, first with insecticides at normal rates and then for ULV spraying. In the first case, using 15 kg/ha to represent insecticides and fungicides, 75 kg/ha to represent herbicides, defoliants and dessicants, and 200 kg/ha to represent fertilizers and seeds, the current breakdown was calculated as follows:

	Developing Countries	Developed Countries
Insect./Fung.	53%	55%
Herb./Def./Dess.	26%	30%
Fert./Seed	21%	15%

TABLE 22

TECHNOLOGY SENSITIVITIES

Percent Change in Application Cost for
10% Increase in Parameter

Airplane	Parameter / Appl. Rate, kg/ha =	Developing Countries Field Size = 50 ha 4	15	75	200	Developed Countries Field Size = 150 ha 4	15	75	200
AgWagon	Lift/Drag	-31.9	-31.9	-31.9	-31.9	-31.9	-31.9	-31.9	-31.9
	Stall Speed	69.2	62.5	39.7	15.2	56.1	48.9	12.0	3.0
	Field Speed	-25.6	-23.1	-14.7	-5.6	-35.9	-31.2	-7.7	-1.9
	Ferry Speed	-0.1	-5.9	-9.3	-17.0	-0.3	-50.6	-310.5	-370.8
	Empty Weight	0.4	5.1	82.4	149.6	2.1	25.3	154.8	184.9
	Load Factor	-67.1	-1.9	-30.3	-55.2	-54.4	-7.8	-47.6	-56.8
	Swath Width	-82.8	-74.8	-47.5	-18.2	-82.3	-71.6	-17.6	-4.4
	Application Rate	0.5	5.8	91.6	166.5	2.3	28.1	172.2	205.6
	Loading Rate	-0.1	-1.6	-25.0	-45.6	-0.5	-6.4	-39.3	-46.8
	Fuel Consumption	0	0.4	6.4	11.7	0.2	2.0	7.8	14.4
	Engine Power/Weight	-0.1	-1.2	-18.9	-34.4	-0.5	-5.8	-35.5	-42.4
Turbo Thrush	Lift/Drag	-28.5	-28.5	-28.5	-28.5	-28.5	-28.5	-28.5	-28.5
	Stall Speed	61.0	58.4	46.1	20.5	47.5	44.8	18.9	4.8
	Field Speed	-35.2	-33.7	-26.6	-15.2	-42.7	-44.8	-18.9	-6.1
	Ferry Speed	0	-0.1	-2.6	-7.1	0	-0.9	-9.7	-14.9
	Empty Weight	0.1	1.7	34.6	93.8	0.6	7.6	80.3	123.2
	Load Factor	-58.2	-55.7	-43.9	-19.7	-45.3	-42.7	-18.0	-4.6
	Swath Width	-82.1	-87.3	-68.8	-39.3	-82.0	-85.9	-36.2	-11.7
	Application Rate	0.2	3.0	59.1	159.9	1.0	13.0	136.9	209.9
	Loading Rate	-0.1	-1.0	-19.6	-53.0	-0.3	-4.0	41.7	-64.0
	Fuel Consumption	0	0.9	4.0	10.7	0.1	0.9	9.2	14.1
	Engine Power/Weight	0	-0.2	-3.3	-8.9	-0.1	-0.7	-7.6	-11.7

Applying these percentages condenses the data in Table 22 considerably, as shown in the upper part of Table 23. A further condensation is possible by averaging the results for the two airplanes. The ranking of technologies which then emerges is given below, where the highest ranking indicates the most favorable cost impact for a specified percentage change in the parameter.

Developing Countries (relatively small fields)	Developed Countries (relatively large fields)
Swath Width	Ferry Speed
Application Rate	Application Rate
Stall Speed	Empty Weight
Empty Weight	Swath Width
Load Factor	Stall Speed
Lift/Drag	Lift/Drag

These results show that the developing-country environment, with its smaller field size, emphasizes performance that minimizes time spent in turns. Therefore a wider swath, combined with reduced stall speed and increased load factor to decrease turning time, are important improvements. The effect of application rate is important in both environments, because it impacts both field time and turn time. Reduced empty weight translates directly into higher payload in this analysis, thereby reducing the need for ferrying. At the larger fields characteristic of a developed-country environment, ferrying becomes a more important factor. Hence, higher ferry speed and lower empty weight are the high-ranked improvements, with swath width and stall speed having lesser impacts, although still important. In summary, the technology improvements which produce the greatest impacts in the developing-country environment are generally the same ones which would be beneficial in developed countries, with some reordering because of the effect of field size.

Using the ULV data (4 kg/ha) in place of the normal insecticide/fungicide data (15 kg/ha) from Table 22, the above process was repeated, resulting in the figures in the lower part of Table 23, and the following ranking.

Developing Countries (relatively small fields)	Developed Countries (relatively large fields)
Swath Width	Ferry Speed
Application Rate	Application Rate
Stall Speed	Empty Weight
Load Factor	Swath Width
Empty Weight	Stall Speed
Lift/Drag	Load/Factor

Comparing this summary with the one shown above for the higher application rate, it is apparent that only minor changes in ranking differentiate the two

TABLE 23

TECHNOLOGY SENSITIVITIES

Percent Change in Application Cost for 10% Increase in Parameter

Insecticides/Fungicides at 15 Kg/ha

Parameter	AgWagon Developing Countries	AgWagon Developed Countries	Turbo Thrush Developing Countries	Turbo Thrush Developed Countries
Lift/Drag	-31.9	-31.9	-28.5	-28.5
Stall Speed	46.6	30.8	47.2	31.0
Field Speed	-17.2	-19.8	-28.0	-31.2
Ferry Speed	-6.3	-176.6	-2.2	-5.6
Empty Weight	55.5	88.1	29.6	46.8
Load Factor	-38.7	-30.3	-45.1	-29.6
Swath Width	-55.8	-45.3	-72.4	-59.9
Application Rate	61.9	98.0	50.5	79.7
Loading Rate	-16.9	-22.4	-16.8	-24.3
Fuel Consumption	4.3	6.9	3.8	5.4
Engine Power/Weight	-12.8	-20.2	-2.8	-5.1

Insecticides/Fungicides at 4 Kg/ha (ULV)

Parameter	AgWagon Developing Countries	AgWagon Developed Countries	Turbo Thrush Developing Countries	Turbo Thrush Developed Countries
Lift/Drag	-31.9	-31.9	-28.5	-28.5
Stall Speed	50.2	34.9	48.6	32.5
Field Speed	-18.6	-22.4	-28.8	-30.1
Ferry Speed	-6.0	-148.9	-2.2	-5.1
Empty Weight	53.1	75.3	28.8	42.9
Load Factor	-48.8	-33.9	-46.4	-31.0
Swath Width	-60.1	-51.2	-69.7	-57.7
Application Rate	59.0	83.8	49.1	73.1
Loading Rate	-16.1	-19.1	-16.3	-22.3
Fuel Consumption	4.1	5.9	3.3	4.9
Engine Power/Weight	-12.2	-17.3	-2.7	-4.1

cases. The fact that application rate is an important parameter in both cases shows the cost reduction potential of going to low application rates. Since ULV offers a significant reduction in the dominant application category (insecticide), its implementation on a wide scale would have a beneficial cost impact on ag-air operations. Therefore, research directed toward proving the practicality of applying insecticides at ULV rates, while maintaining environmental standards, should be an important element of the NASA program.

The effect of an expansion of ULV spraying would have the effect of de-emphasizing large aircraft requirements, which would be in direct opposition to trends described earlier. However, whereas low-volume applications would be best accommodated by small-size airplanes, there would be no appreciable effect on fleet requirements if ULV rates were to be adopted for insecticide spraying. The reason fleet requirements would not change is that reducing the application rate from 15 to 4 kg/ha has very little impact on aircraft productivity (ha/hr), as pointed out earlier. Therefore, with the same amount of area to be treated, the number of airplanes required would decrease only slightly.

Case Study

An interview with one of the most knowledgeable Colombian operators* revealed some interesting comments concerning perceived technology needs. These comments do not represent an exhaustive survey, even for Colombia, and in some respects they duplicate technology priorities in the US, as advanced in Ref. 42, for example. Also, they may be too specific with respect to the particular aircraft models being utilized by this operator. Nevertheless, the comments are useful because they provide some insight into the perceptions of a developing-country operator. The technical improvements listed below are divided into three general groups, but the ordering does not reflect any prioritization of the individual items.

Category	Suggested Improvement
Emergency Features	Collapsible Gear Rapid Fuel Dump Master Kill Switch
General Safety Features	Relocate Fuel Tanks Slack Fuel Lines Display of Measured Torque
Design	Display of Hopper Contents Improved Engine Cooling

*Mr. William R. Griebling, owner of Sanidad Vegetal Ltda. in Ibagué, Colombia.

Design (cont'd)

Higher Tailplane
Noncorrosive Materials
Improved Control Linkages
New Spray Method

The emergency features reflect a concern both for the safety of the pilot in a power-loss emergency situation, and to permit a controlled crash in which damage to the airplane is minimized. Thus, the improvements involve both the impact of the aircraft with the ground, and the potential for fire subsequent to the impact. The collapsible gear and rapid fuel dump features of the Ag Cat were mentioned as design practice which should be universal*. The master kill switch referred to might perform several functions simultaneously in a situation where the time available to the pilot is severely limited. Among these might be deactivation of all electrical accessories to prevent spark-ignited fires, jettisoning of fuel and/or payload to increase glide time, and opening of the canopy to permit rapid escape.

The second group includes general safety features, although these would also be useful in a power-loss emergency. Relocation of the fuel tanks means making them more remote from the engine; the possibility of breakaway tanks was mentioned. Slack in the fuel lines behind the firewall would make them less likely to break on impact and thereby reduce the potential for fire. As an aid to the pilot in making a go/no-go decision on take-off, strain gauges might be mounted to measure engine torque, with an appropriate display to the pilot. Similarly, under the design category, a strain gauge on the hopper would measure the actual load being carried. In the developing-country environment, poor quality control on materials may introduce a significant error if the load is calculated from the indicated weight of bagged materials. A measuring device on the airplane would preclude overloading.

Improved engine cooling was cited as a means of conserving power. The desirability of raising the tailplane was prompted by the frequency of tailplane damage from debris. This comment is probably also a reflection of the poor quality of runways from which developing-country operators may have to operate. More extensive use of noncorrosive materials is self-explanatory in view of the corrosive nature of chemical sprays and granular materials. Difficulty in obtaining spare parts and a shortage of repair skills would be additional reasons to replace metallic parts which are subject to corrosion. Improved control linkage materials were mentioned in this same connection, corrosion of linkages having been a continuing problem. The possibility of fly-by-wire controls was suggested, providing the electrical parts could be kept free of dust.

The last item on the list refers to a conviction that "nozzles are not the answer" to the need for a reliable system of uniform spraying. Nozzle

*Note that the Ag Cat is not available to Colombian operators without imposition of a rather high duty.

wear and plugging are severe problems, perhaps accentuated by poor quality control of materials. The poor distribution and added expense of operating with inefficient nozzles prompted this operator to suggest that an alternative to nozzles be sought, although he was unable to be specific about the nature of such an alternative.

Finally, some specific problems of developing countries should be mentioned as they affect future technology needs. The relatively poor infrastructure of developing countries, in both the physical and technological sense, presents problems not usually encountered in developed countries. For example, the poor quality control in dispersible materials creates special problems for the operator. He may be in doubt about the weight and dilution of the product, thereby introducing application errors over which he has no control. Poor results may then be ascribed to his technique, with subsequent loss of business. Lack of available runways may impose unduly long ferry requirements. The alternative of establishing good local runways is open only if the operator can bear the expense. The fact that governments do not yet recognize ag-air as an industry deserving of preferential treatment means that large capital outlays are difficult to justify. This policy may have a particularly detrimental effect on the introduction of turbine-powered ag-airplanes because of their high cost. Even if an operator were convinced of the need for an airplane with the productivity potential of turbine power, the big capital outlay would be a severe impediment, particularly if it were complicated by a payment-in-advance requirement in US dollars.

Another problem which could limit the adaptation of new technology in developing countries is the continued trend toward domestic manufacture of US aircraft under license. Government programs to foster development of domestic aircraft industries will attempt to integrate more and more of the primary manufacturing steps. Limitations on available technical skills could preclude integration of complex manufacturing processes or use of exotic materials. Therefore, if technology improvements incorporate such complications their acceptance by developing countries may be jeopardized.

CONCLUSIONS

World Market Study

1. The US general aviation manufacturers will continue to supply most of the agricultural aircraft required in free-world markets. Poland could emerge as a competitor, and many developing countries will attempt to protect nascent aircraft manufacturing industries by imposing high tarrifs on imports from the US. For this reason, a continuation of the present trend toward licensing of foreign firms to assemble US models can be expected Moreover, increased integration of basic manufacturing processes into the domestic programs will be required by developing countries to foster growth of local aviation manufacturing industries.

2. The US domestic market will continue to be the major recipient of US aircraft, but foreign markets will grow in relative importance during the forecast period. The predicted growth of the US and world fleets are shown in Figs. 79 and 80. Among the foreign markets, Latin America is the largest regional market for US ag-aircraft export shipments, and will remain the largest despite higher growth rates in the developed-country and Asian markets.

3. The world ag-air industry will experience continued expansion in treated area at about a 4.5%/year growth rate. The North American market will grow at more than 5%/year, the other free-world markets at just under 4%/year, and the communist group at just over 4%/year. The US will be the fastest-growing market, overtaking the USSR in treated area before the end of the century. Aircraft fleets will grow more slowly because of increasing productivities and because the future fleets will have higher percentages of large aircraft.

4. Field size is an important determinant of ag-air activity. Therefore ag-aircraft fleets are most numerous in regions where the percentage of large fields is high. In the development of the forecast methodology it was determined that the percentage of cropland area in holdings larger than 100 hectares is a good criterion to explain the present world ag-air market.

Economics and Technology

1. Since the cost of aerial application is typically higher than for ground equipment, the choice of aerial application is made because of other factors, such as terrain, soil compaction, and proper timing. The growth of ag-air is a direct result of increased awareness by farmers that these factors have economic significance which goes beyond the cost of the application. Education is therefore an important aspect of ag-air growth, particularly in the developing world where technical knowledge is lacking.

NOMINAL PROJECTION OF US AGRICULTURAL AIRCRAFT FLEET

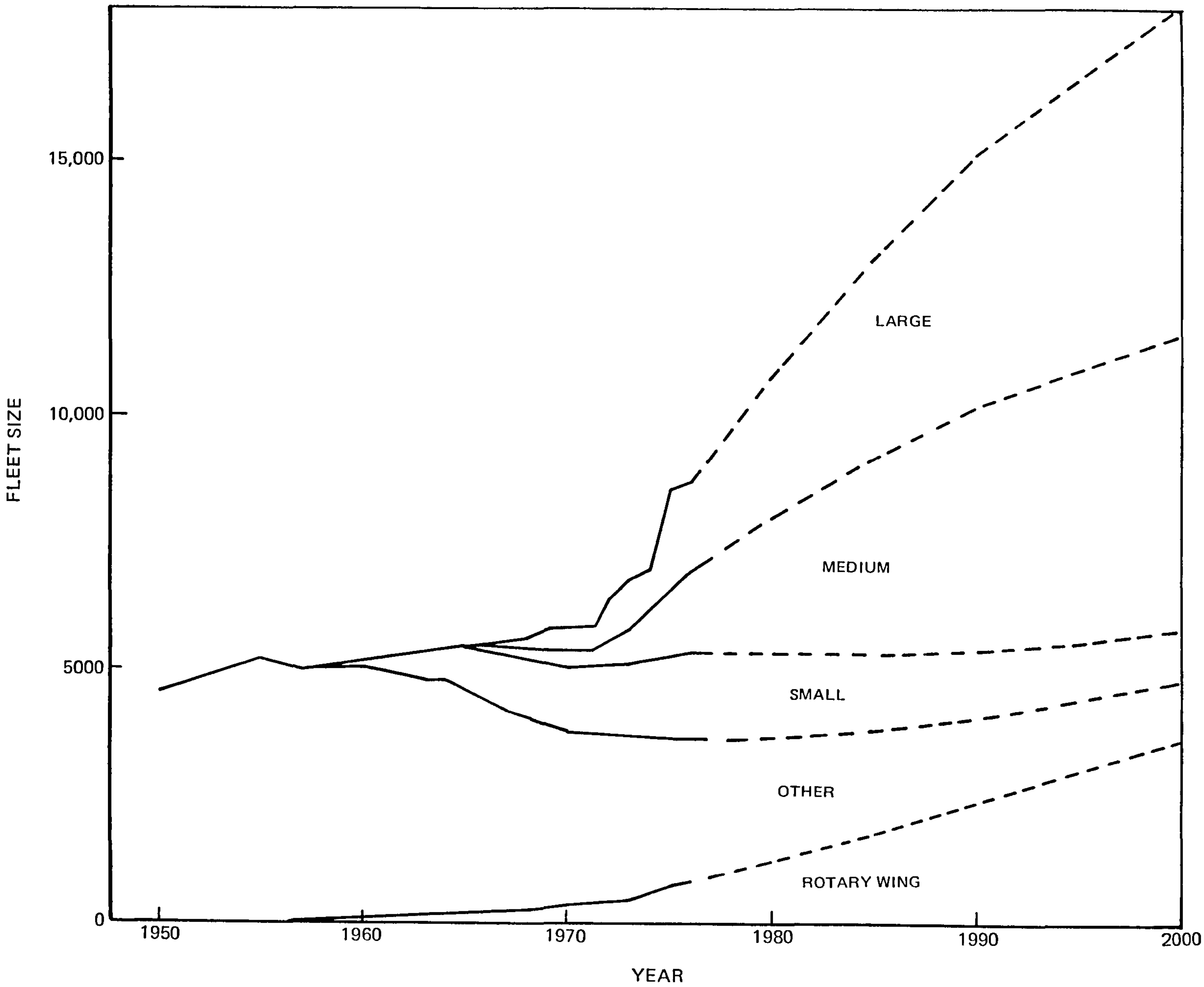


FIG. 79

79–01–255–4

NOMINAL PROJECTION OF WORLD AG–AIR FLEET

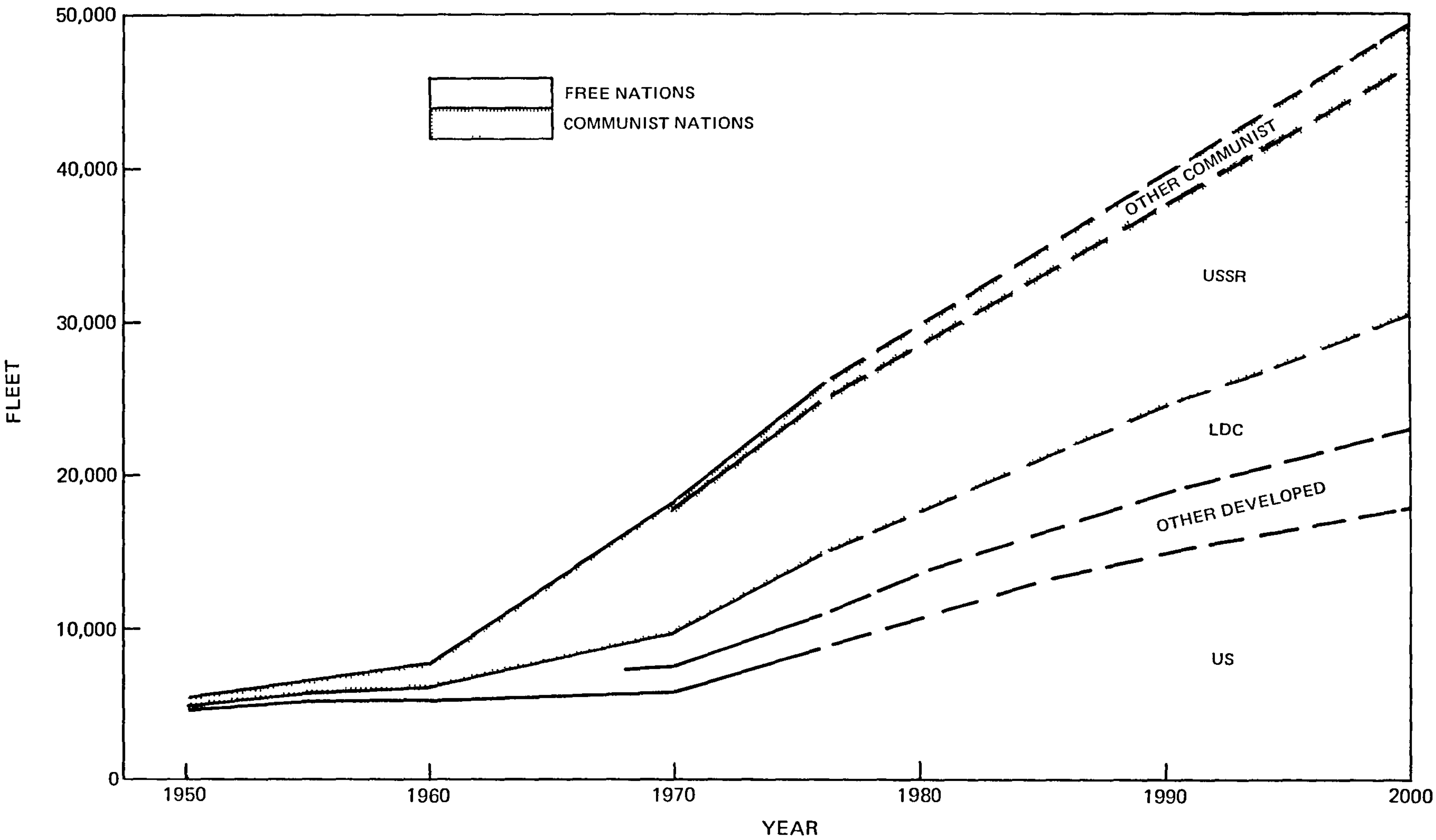


FIG. 80

79–01–255–17

2. The cost of dispersible materials (insecticide, herbicide, fertilizer, etc.) is generally much higher than the cost of application when both are expressed on a cost per unit area basis. Therefore, operating cost differences among aircraft may be less important than often assumed. For example, a 5 percent reduction in the cost of typical materials would justify a 50 percent increase in aircraft-related costs. Consequently, introduction of advanced technology can be cost-effective if economies in material use can be demonstrated through more uniform or more precise spraying. For this reason, distribution systems and guidance are technology areas which should be stressed. However, the cost trade-off between implementation of a specific technology and realization of yield improvements and material cost savings should be established.

3. A ranking of worthwhile technological improvements to aircraft differs slightly between developing and developed countries. In terms of decreasing payoff for equal percentage improvements in each of the following parameters, the ranking is as follows:

Developing Countries	Developed Countries
Swath Width	Ferry Speed
Application Rate	Application Rate
Stall Speed	Empty Weight
Empty Weight	Swath Width
Load Factor	Stall Speed
Lift/Drag	Lift/Drag

This ranking does not change significantly if ULV rates are used in place of normal insecticide application rates. The driving factor for developing countries is small field size, which emphasizes turning performance and large swath width to minimize the turns required. For the larger fields characteristic of a developed country, increased payload and reduced ferry time have greatest payoff with, again, increased swath width to improve field coverage. For the larger aircraft which may be required, gas turbine propulsion would serve to reduce empty weight with a corresponding increase in payload. Application rate is a highly ranked parameter for both developing and developed country conditions. Since the primary opportunity for reduction in application rate is by ULV spraying of insecticides, research to make ULV practical and environmentally acceptable should be an important element of the NASA program.

4. The relationship between the grower and the applicator has a direct bearing on the adoption of technological improvements. If the applicator purchases the chemicals he will be inclined to seek good distribution and achieve a minimum waste. If the grower purchases the materials, the applicator will be less careful in his application. The latter situation now exists in Colombia.

5. At low application rates, the cost of using small aircraft is less than that of large aircraft. However, while the relative difference between small and large aircraft is great, the absolute cost difference is small, and materials costs dominate anyway. Large airplanes compare much more favorably at high application rates, where applications and materials costs are comparable. Therefore, large aircraft are more competitive than generally assumed.

Aircraft Types

1. There is good reason to believe that aerial fertilization and seeding will grow rapidly relative to application of chemical agents. High growth in the production of rice and other grains relative to cotton will result in a gradual trend in this direction. However, the present experience of the USSR, where fertilization accounts for 50 percent of all aerial treatment area, suggests a potential revolution in practice in the next two decades. If this revolution in practice comes about, strong growth in sales of large ag-aircraft is forecast, including very large advanced models with turbine power.

2. If technological progress permits wide-scale use of ULV spraying of insectides, a trend back toward smaller ag-aircraft would occur. However, fleet size would be affected only slightly because aircraft productivity (ha/hr) increases only slightly when application rate is reduced from normal insectide rates (15 kg/ha) to ULV rates (4 kg/ha).

3. Rotary-wing aircraft, which presently comprise only 9 percent of the US fleet, will increase their share to about 20 percent by 2000. This growth will be driven partly by environmental controls and partly by strong growth in vegetable and fruit production. The 20 percent fleet component will bring the US closer to present experience in the USSR and other developed countries.

Case Study of Colombia

Present Fleet and Technology

1. Colombia is a very important agricultural country in South America and is a major user of US ag-aircraft. Cotton and rice comprise 80% of the aerial treatment area in Colombia. The great majority of ag-aircraft in the Colombian fleet are Cessna and Piper models, which are produced under license by Colombian firms. Increased integration of manufacturing in the domestic industry is prescribed by government policy. Although some adaptations to local conditions are made in the production of these aircraft, e.g., soft-field gear, they are almost identical to models produced in the US.

Since there is a shortage of technical skills in Colombia, increased integration of primary manufacturing processes could impede incorporation of advanced-technology features.

2. The Colombian market will continue to be an important one for US manufacturers, since airplanes in current use are appropriate for typical Colombian cotton and rice fields.

3. New aerial applications technology could be economically feasible if it resulted in improved cotton and rice yields. For example, a 10% increase in cotton yield may justify a doubling of application cost.

Aerial Application Industry

1. The Columbian ag-air industry is fragmented, and aerial applications practice is often poor because of lack of knowledge. Government policy of free enterprise allows competition among ag-air operators, who must be licensed to operate. However, the government is unable to control activities of unregistered "pirate" operators, and poor practice has prompted the government to exercise more control over the industry. Environmental issues are receiving major attention as a result of close contact between Colombian and US government and industry leaders. Biological controls and an integrated approach to pest management are elements of government policy which will affect future uses of aircraft.

2. There is a general lack of government support for the ag-air industry. Whereas substantial financial advantages are offered to encourage purchase of farm machinery, ag-aircraft financing is unassisted. Shortage of equity capital and inflation are additional impediments to aircraft purchases in Colombia. A land reform program implemented in the 1960s had the effect of breaking up large agricultural holdings and thus reducing average field size. However, the program is not being actively pursued by the present government.

3. As in many developing countries, the physical and technical infrastructures are poorly developed. Lack of parts availability, spot shortages of chemicals, and crude runways are facts of life for Colombian operators. Poor quality control over materials is a persistent problem. Improper dilution, inaccurate labeling and outright theft are common in the distribution chain.

Future Outlook

1. Most crop production is on unirrigated fields, and crop seasons are dictated by the favorable climate. Increased irrigation of fields could permit multiple cropping, with direct advantages to the ag-air industry because of the greater importance of proper timing. The advantage of aerial application in shortening the growing season of each crop would then assume greater importance.

2. The Llanos is a vast region of great agricultural potential which is just being exploited. Inaccessibility and field size characteristics in this region will favor use of airplanes, and large airplanes may be especially beneficial.

3. Based on present government policy, ultra-low volume (ULV) applications will be curtailed for environmental reasons. The need for very accurate calibration of equipment is cited as the basic problem. Such accuracy is considered beyond the capability of operators. Even if the safe application of chemicals in concentrated form could be demonstrated, the ability of Colombian operators to implement ULV safely will be in doubt.

Technology Improvements

1. Specific technology improvements to either enhance operational characteristics or increase safety were suggested by operators in Colombia. Recommended improvements of operational characteristics are as follows:

- Display of Hopper Contents -- to avoid overloading or underloading
- Improved Engine Cooling -- to conserve power
- Higher Tailplane -- to avoid damage from debris
- Noncorrosive Materials -- to reduce corrosion of aircraft
- Improved Control Linkages -- to avoid deterioration due to corrosion
- New Spray Method -- to improve distribution of dispersed materials

2. Recommended improvements for increased safety are as follows:

- Collapsible Gear -- to limit damage in a controlled crash
- Rapid Fuel Dump -- to minimize fire danger in crash or emergency landing
- Master Kill Switch -- to deactivate electrical accessories, dump payload and fuel, and jettison canopy
- Relocate Fuel Tanks -- more remote from engine, possibly with breakaway tanks
- Slack Fuel Lines -- to avoid breakage in a high-stress condition
- Display of Measured Torque -- to facilitate go/no-go decision on takeoff

REFERENCES

1. Akesson, N. B. and W. B. Yates: The Use of Aircraft in Agriculture. Food and Agriculture Organization of the United Nations, Rome, 1974.

2. Nazarov, V. A.: Aircraft Use in Agriculture and Forestry. NASA TT F-16, 846, February 1976.

3. FAO Production Yearbook, 1976, Vol. 30, Food and Agriculture Organization of the United Nations, Rome, 1977.

4. Reutlinger, S. and M. Selowsky: The Anatomy of Hunger-World Bank Occasional Staff Paper 23, 1976.

5. Gill, R. T.· Economic Development: Past and Present. Prentice-Hall, Inc. Englewood Cliffs, N.J., 1967.

6. World Bank Annual Report 1977. World Bank, Washington, D.C.

7. Population and Food - Crucial Issues. Committee on World Food, Health and Population of the National Academy of Sciences, Washington, D.C., PB 248 257, September 1975.

8. Holmes, B. J.: Overview of NASA Aerial Applications Research. ASAE Paper No. 78-1505, Presented at the 1978 Winter Meeting of the American Society of Agricultural Engineers, Chicago, Ill, December 1978.

9. FAA Statistical Handbook of Aviation. U.S. Dept. of Transportation, Federal Aviation Administration, 1946 through 1976.

10. Hazelrigg, G. A.: The Benefits of Improved Technologies in Agricultural Aviation. NASA CR-156838, February 1978.

11. Wheeler, A. H.: The Future for Agricultural Aviation. Aeronautical Journal of the Royal Aeronautical Society, March 1968.

12. General Aviation Aircraft Fleet. GAMA's Aircraft Fleet Directory. General Aviation Manufacturers Association, Washington, D.C., 1978.

13. Jane's All the World's Aircraft, 1977-78. John W. R. Taylor, Editor. Library of Congress Catalogue No. 75-15174.

14. Aviation and Agriculture - A Developing Partnership. Interavia, February 1978, pp. 117-119.

REFERENCES (Cont'd)

15. US Agricultural Aircraft. Aviation Week and Space Technology. Aerospace Forecast and Inventory Issue, March 13, 1978, p. 121.

16. Garrison, Paul: Economics of Operating Business Twins. Flight Operations, February 1977, pp. 15-19.

17. Gobetz, F. W., R. J. Assarabowski, and A. A. LeShane: Applications of Advanced Transport Aircraft in Developing Countries. NASA CR-145343, May 1978.

18. Głos Wybrzeża, July 26, 1973, p. 3.

19. Agricultural Aviation in Brazil and India. A Sharp Contrast. Interavia, December 1976, pp. 1158-1159.

20. Paris Air Show - Brazil Seeking New Aircraft Markets. Aviation Week and Space Technology, June 27, 1977, pp. 63-66.

21. North, David M.: Agricultural Aircraft Sales Rise Foreseen. Aviation Week and Space Technology, September 26, 1977, pp. 85-89.

22. Wetmore, Warren C.: Poles Demonstrate Turbofan Biplane. Aviation Week and Space Technology, June 27, 1977, pp. 69-70.

23. Syrzydlata Polska, Nos. 1-53, 1973; Nos. 1-50, 1974.

24. Bernet, Edwin E.: The Chemical Industry's Contribution to Agricultural Aviation. The World of Agricultural Aviation, Vol. 2, No. 10, October 1975, pp. 18, 24-30.

25. Report on the 1960 World Census of Agriculture, Analysis and International Comparison of Census Results. Vol. V, Food and Agriculture Organization of the United Nations, Rome 1971.

26. Land Reform-Sector Policy Paper, World Bank, May 1975.

27. Historical Statistics of the United States, Colonial Times to 1970. U.S. Dept. of Commerce, Bureau of the Census, Bicentennial Edition, 1975.

28. Statistical Abstract of the United States. U.S. Dept of Commerce, Bureau of the Census, 98th Annual Ed., 1977.

29. Blight of the Tropics. Newsweek, June 26, 1978, Medicine Section.

30. Rainey, R. C.: Aircraft in the Control of Desert Locust Swarms. Cranfield Inst. of Aero. Short Course, Aerial Application of Pesticides, 1976.

31. Alsop, N. J.: Aircraft in Test Control Programs. Cranfield Inst. of Aero. Short Course, Aerial Application of Pesticides, 1976.

32. Hinely, J. T., Jr. and R. Q. Boyles, Jr.· Advanced System Design Requirements for Large and Small Fixed-Wing Aerial Applications Systems for Agriculture. NASA CR-158939, January 1979.

33. Nebraska Tractor Test Data. Agricultural Engineers Yearbook - 1978. American Society of Agricultural Engineers, 1978.

34. Agricultural Machinery Management. Agricultural Engineers Yearbook - 1978. ASAE Engineering Practice, ASAE EP391, 1978.

35. Agricultural Machinery Management Data. Agricultural Engineers Yearbook - 1978. ASAE Data, ASAE D2330.3, 1978.

36. Hi-Cycle and other Sprayers. John Deere sales literature, December 1978.

37. Forest Fertilization Theory and Practice. Proceedings of the Symposium on Forest Fertilization, April 1967 at Gainesville, Florida.

38. Avramovic, Dragoslav. Economic Growth of Colombia: Problems and Prospects. Report of a mission sent to Colombia in 1970 by the World Bank. World Bank Country Economic Report, The Johns Hopkins University Press, Baltimore and London, 1972.

39. Ministerio de Agricultura: Cifras del Sector Agropecuario. Anexo Memoria No. 1, Bogotá, Colombia, October 1977.

40. Federacion Nacional de Algodoneros. Informe del Gerente al XVII Congreso Nacional de Algodoneros, Bogotá, October 1978.

41. Federcion Nacional de Algodoneros. Costos de Produccion de Algodon (Costs of cotton production for various regions). Dirección Estudios Economicos, 1975-1978.

42. Agricultural Aviation Research. NASA Conference Publication 2025. A workshop held at Texas A&M University, October 19-21, 1976.

43. Wellhausen, Edwin J.: The Agriculture of Mexico. Scientific American, Vol. 235, No. 3, September 1976.

APPENDIX

LAND DISTRIBUTION IN COLOMBIA

As indicated in the text, field size is an important determinant of agricultural airplane use. It would be useful to have distributions of field size in order to determine the penetration of ag-aircraft for chemical and fertilizer application. The only available indication of land use in Colombia is the 1960 agricultural census (Ref. 25), which was undertaken prior to land reform. The effect of land reform was to increase the number of very small fields without significantly affecting larger fields. Only the latter are of interest for aerial application, so the census can be assumed to be reasonably valid as an indication of land distribution for all crops.

It is essential to make a distinction between "farms", "cropland" and "field size". A farm consists of a variety of land uses, of which only a portion are devoted to cropland. The "cropland" consists of land used for permanent and temporary crops, and fallow land. The temporary and permanent crops are those which might receive aerial application. Finally, the actual field size (i.e., plot) is some fraction of the temporary and permanent crops. Typically, growers subdivide their total planted area into smaller plots because of terrain, accessibility and the number of different crops planted. Because no data are available in how Colombian growers allocate their planted fields, "field size" is assumed to be equivalent to cropland, i.e., the sum of temporary, permanent and fallow land. This assumption will result in field size estimates that are biased upward. However, for the large fields on which aerial applications are concentrated, the estimates should be fairly good.

Figure A1 shows the land use distribution for all farmers in Colombia. Small farms are farmed very intensively, i.e. have the largest proportion of temporary and permanent crops. (Land for coffee production, for example, is part of the permanent crop category for small farms.) This proportion decreases with farm size, as pasture and unused land (mountains, forests and other) become predominant. Above 200 ha, however, these other uses decrease as large tracts are apparently converted to pasture (e.g. large ranches). Fallow land is an approximately constant proportion of all farms, but its area is much larger for large farms, as will be seen.

An important assumption made in determining the average field size for aerial application was that large fields are more likely to utilize aerial application than smaller fields. For a given field size distribution and total area (F), the area using aerial application (f) will consist of all fields larger than some size, such that f/F is equal to the fraction of

DISTRIBUTION OF LAND USE WITHIN FARMS IN COLOMBIA

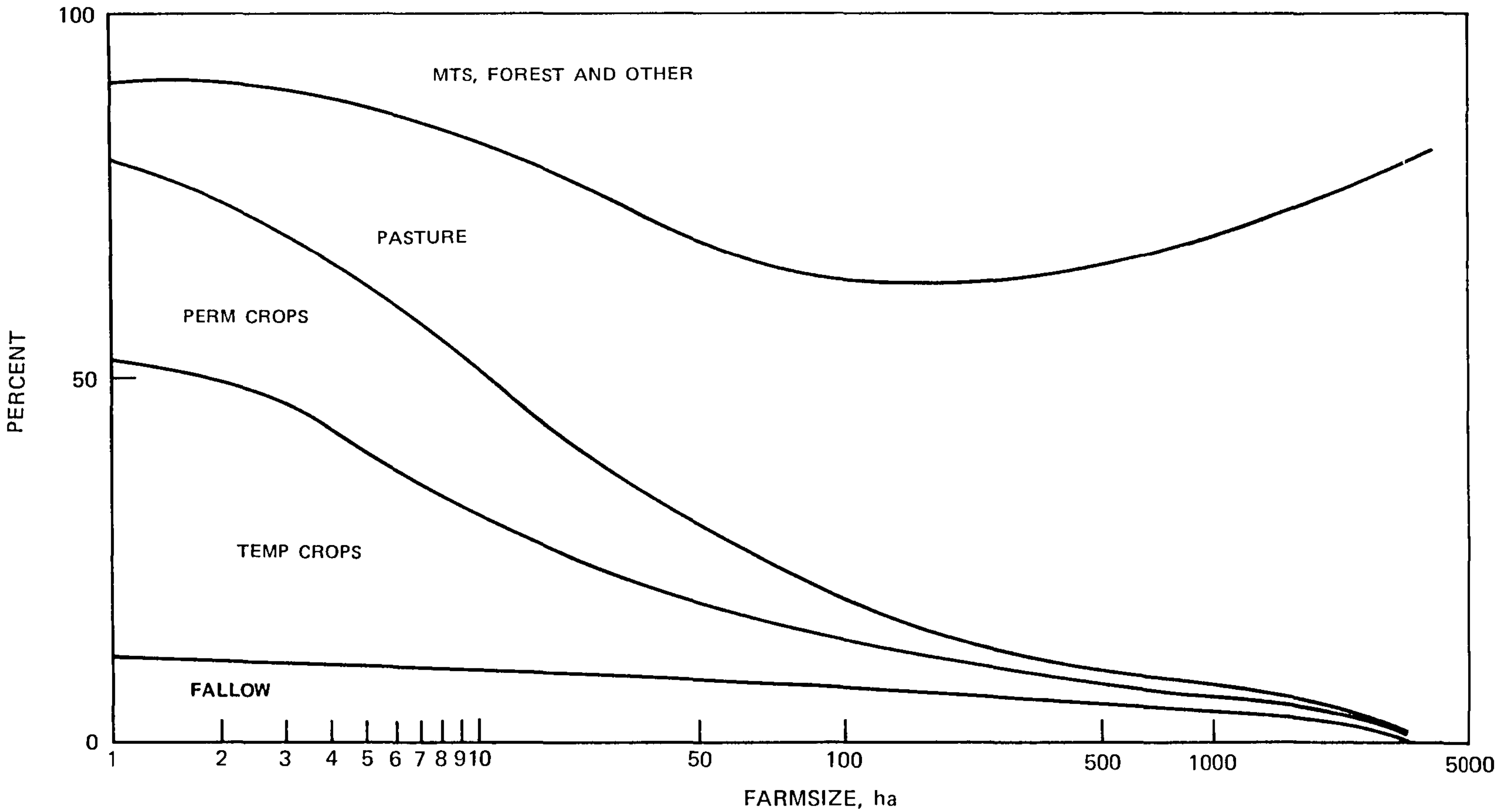


FIG A1

79-02-2-1

fields using aerial application. The parameter used in describing this area is "field size above X" where X is the minimum field size using aerial application.

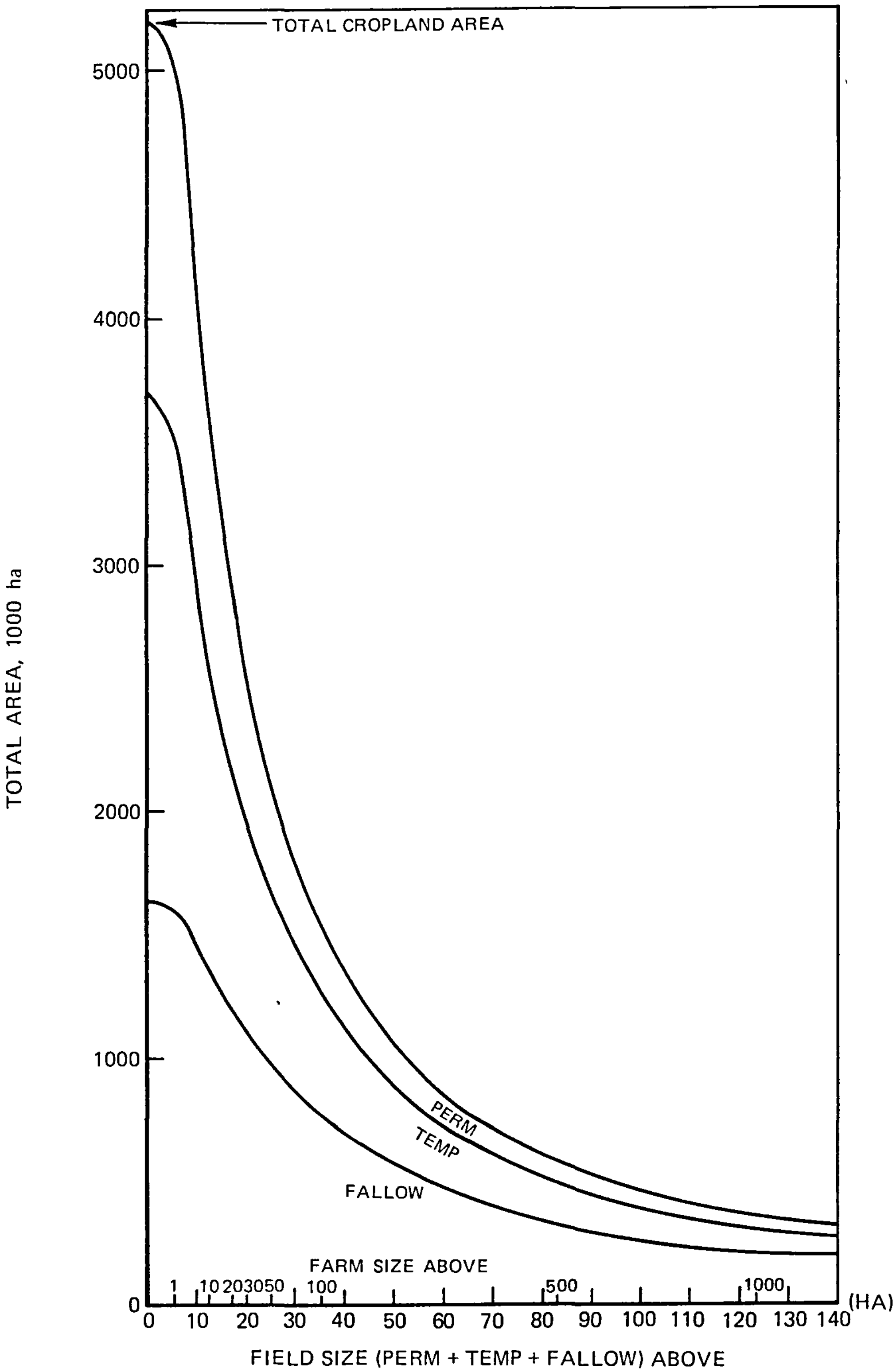
Figure A2 shows a plot of the total cropland area for fields above a given size, shown on the X-axis. The corresponding farm size is shown on the same axis. It can be seen that one-half of all cropland in Colombia is on farms of less than 30 ha. This implies that, even if airplanes could be used to spray all fields above 30 ha for all crops, only one-half the cropland would be covered. The actual field size would be even smaller because of fallow land and further subdivision of fields. Clearly, then, only a small percentage of total area could possibly be penetrated by ag-aircraft.

If the area in Fig. A2 is divided by the number of farms in each farm size category, the resulting curves show the average area of each land use above a minimum cropland size. In Colombia the large number of very small-scale farms results in predominance of very small fields. As the minimum field size is increased, the average area increases, particularly for fallow land. If expansion of area planted occurs in the future, it is likely that fallow land would be planted first. Although most of the fallow land is on small farms (Fig. A2), large holdings of fallow land are also contained on the larger farms (Fig. A3). The planted field size of future expansion could increase or decrease, depending on land reform policy. If expansion were to occur solely by planting large areas of fallow land contained in large farms (without further subdivision), significant increase of average field size could occur with greater possibilities for mechanization, including aerial application.

Although the data presented so far are revealing, they are not appropriate for determining field sizes for particular crops using aerial application. The majority of crops included in the data (such as subsistence crops, etc.) use surface means of application, if any at all. It therefore becomes necessary to do a breakdown by individual crops. Such data are provided in the 1960 agricultural census as area planted to different crops according to farm size. For each farm size category, the planted area and number of farms are shown, such that the average planted field size can be determined. Figure A4 shows the average field size as a proportion of total area for cotton and rice. Unlike Fig. A2, which shows area above a given field size, Fig. A4 shows the area (as a proportion of total area) for a given average field size. That is, the average planted field size represents the average of all fields from large to small. It can be seen that the average field sizes of cotton and rice are 12.2 ha and 4.3 ha, respectively. These averages correspond to 100 percent of the area (all fields greater than 0 ha). As average field size increases, the minimum cut-off increases, and the proportion of the area above some minimum cut-off is shown on the Y-axis.

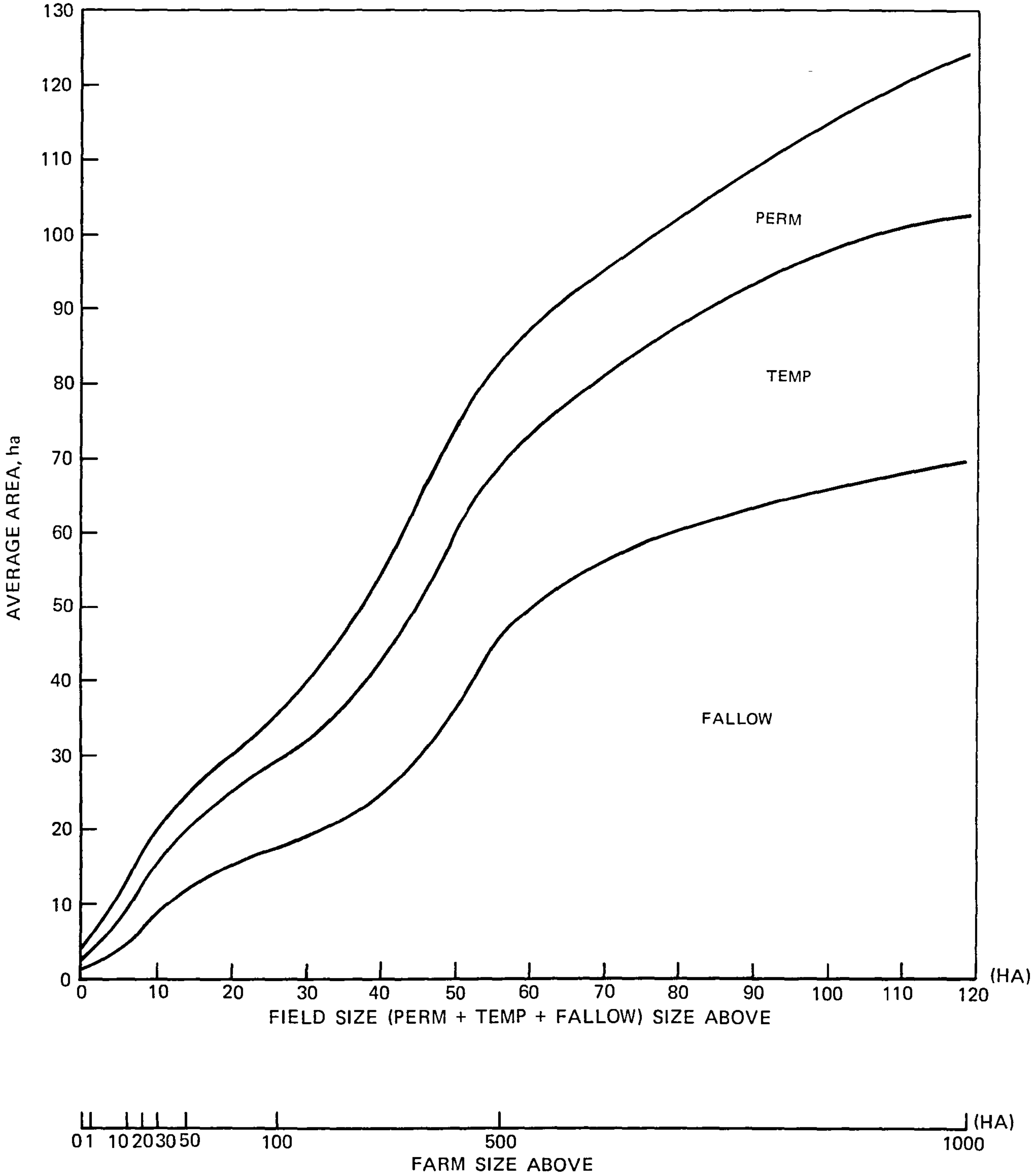
FIG A2

TOTAL CROPLAND AREA ABOVE A MINIMUM FIELD SIZE



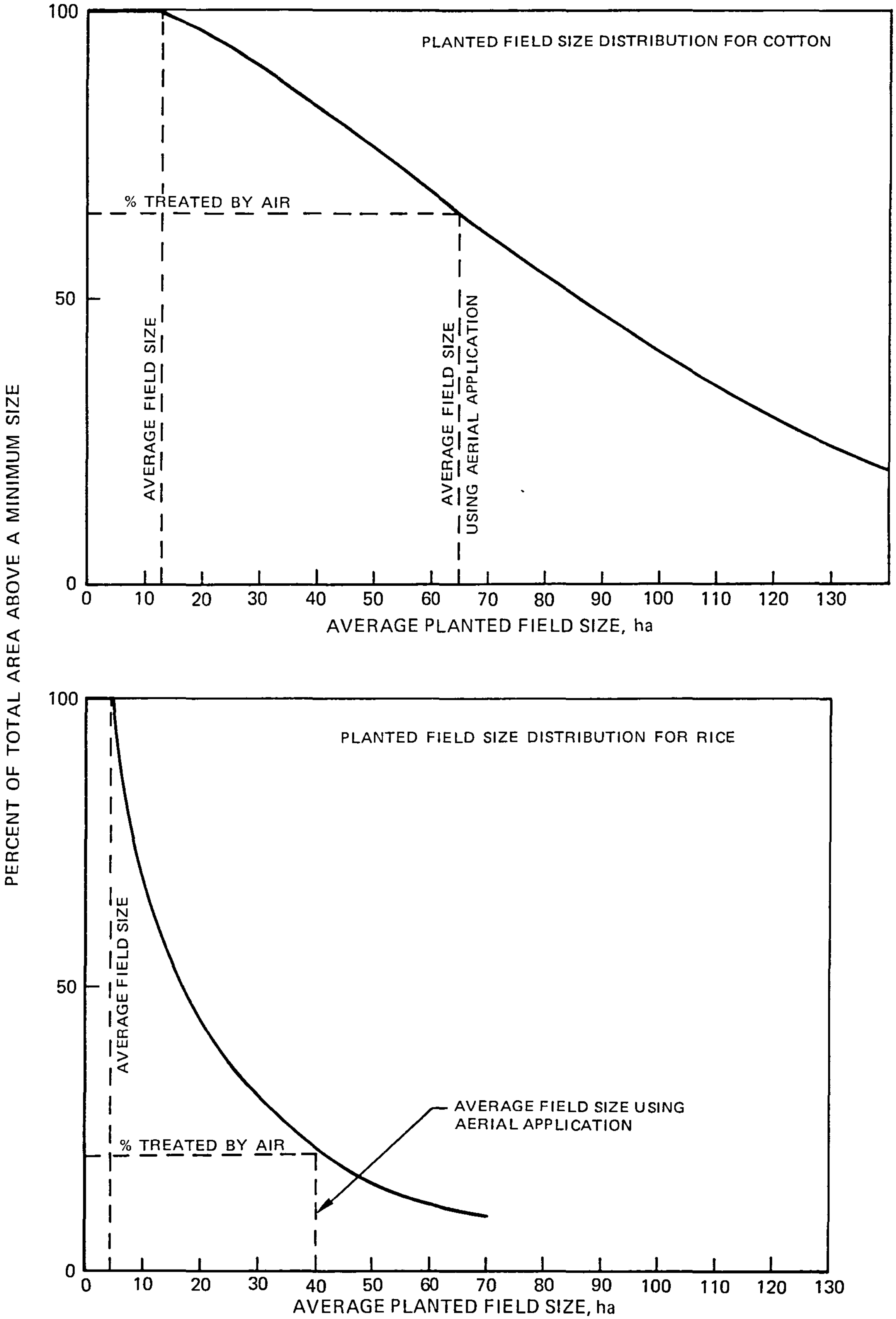
79–02–2–2

AVERAGE AREA OF LAND USES



79–02–2–3

PLANTED FIELD SIZE DISTRIBUTION FOR COTTON AND RICE



79—02—2—4

The proportion of aerial application for each crop was obtained by first calculating the area sprayed for each crop (using the total area (Ref. 39). It was estimated that 65 percent of the cotton and about 20 percent of the rice are treated by air, corresponding to average field sizes of 65 ha and 40 ha, respectively. These estimates of average field size were used for the aircraft analyses in the case study.

LIST OF CONTACTS IN COLOMBIA

Aerial Applicator Association	Mr. Luis Fernando Gutierrez AVIAGRICOLA Carrera 8, No. 62-40 Apartado Aéreo 26770 Bogotá
Agricultural Research & Extension	Dr. Elkim Bustamante INSTITUTO COLOMBIANO AGROPECUARIO (ICA) Apartado Aéreo 7984 Bogotá
Ministry of Agriculture	Mrs. Raquel Bustamante de Henao MINISTERIO DE AGRICULTURA Unidad Agricola - OPSA Carrera 10 #20-30 of. 701 Bogotá
Chemical Companies	Mr. Manuel Castro DOW CHEMICAL OF COLOMBIA Apartado Aereo 12349 Bogotá
	Dr. Michael D. Mowlam SHELL COLOMBIA, S.A. Division Agricola Apartado Aereo 3439 Bogotá
Piper Representative	Mr. James G. Leaver AERO-MERCANTIL LEAVER & CIA S.C.A. Apartado Aéreo No. 6781 Bogotá
Piper Assembly	Col. Alvaro Sarmiento Landinez, Director Mr. Francisco Restrepo Ortega, Asst. Director AERO INDUSTRIAL COLOMBIANA S.A. Apartado Aéreo 92596 Bogotá
Cessna Assembly	Mr. Hector Paez, Asst. Director AVIONES DE COLOMBIA S.A. Apartado Aéreo 6876 Bogotá

LIST OF CONTACTS IN COLOMBIA (Cont'd)

Cotton Growers Federation	Mr. Silvio Alvarado Aguilera Mr. Jairo Cadena Rivera FEDERACION NACIONAL DE ALGODONEROS Direccion de Estudios Economicos Carrera 8 No. 15-73 Bogotá
Aerial Applicators	Mr. William R. Griebling SANIDAD VEGETAL LTDA. Carrera 2a-A No. 14-24 Ibagué, Tolima
	ESTRA CIA. Espinal, Tolima

PROJECTIONS OF CROP PRODUCTION

Projections of crop production were made for the major regional markets by establishing historical growth rates in each crop category applying these growth rates to average production volumes in the 1974 to 1976 period. The growth rates were based on approximately 15 years of historical production figures dating to the early 1960s. Conversion of production volumes to aerial treatment area was then made by the method described in the text, each regional market being characterized by a field size criterion which relates it to 1976 US practice. The tables which follow summarize data for each regional market. Aggregations to major world groupings appear as Tables 8 to 11 in the main text.

TABLE A1

PROJECTIONS FOR NORTH AMERICA

Crop Category	Production			Treated Area		
	1974-76 Av. Prod. 10^9 kg	Avg. Gr. Rate %/yr	2000 Prod. 10^9 kg	1975 Area 10^6 kg	2000 Area 10^6 ha	Avg. Gr. Rate %/yr
Wheat	73.1	3.5	172.8	7.3	32.6	6.2
Rice	5.4	4.8	17.4	12.9	78.5	7.5
Corn	144.5	3.4	333.3	4.2	18.2	6.1
Sorghum	17.9	2.1	30.1	4.4	14.0	4.7
Roots	18.6	1.7	28.4	2.1	5.9	4.3
Dry Beans	0.9	0.4	1.0	1.9	3.9	3.0
Soybeans	40.4	4.0	107.7	5.4	27.2	6.7
Other Grains	19.1	3.2	42.0	4.5	18.8	5.9
Nuts	2.1	5.4	7.9	1.3	8.9	8.1
Sugar	50.4	1.9	80.6	0.6	1.8	4.5
Cotton	5.7	-1.0	4.4	18.5	27.2	1.5
Vegetables	25.5	1.9	40.9	5.1	15.5	4.5
Citrus	12.9	5.7	51.7	1.5	11.6	8.4
Other Fruit	11.7	0.4	12.9	0.6	1.2	3.0
Tobacco	1.1	-0.1	1.0	0.4	0.6	2.5
Timber*	0.77	0.9	0.96	0.2	0.6	4.5
Rangeland*	158	0.7	188	3.3	7.4	3.5
Area Insects*	493	-0.2	469	1.0	1.8	2.4
TOTAL				75.2	275.9	5.3

* In units indicated in Table 5

TABLE A2

PROJECTIONS FOR OCEANIA

	Production			Treated Area		
Crop Category	1974-76 Av. Prod. 10^9 kg	Avg. Gr. Rate %/yr	2000 Prod. 10^9 kg	1975 Area 10^6 kg	2000 Area 10^6 ha	Avg. Gr. Rate %/yr
Wheat	12.1	3.0	25.3	1.2	2.8	3.4
Rice	0.4	8.7	3.5	1.0	9.1	9.1
Corn	0.3	4.1	0.9	<0.1	<0.1	4.5
Sorghum	1.0	10.0	11.2	0.3	3.0	10.4
Roots	2.4	1.5	3.4	0.3	0.4	1.9
Dry Beans	0.1	7.9	0.5	0.2	1.2	8.3
Soybeans	0.1	10.0	1.3	<0.1	0.2	10.0
Other Grains	3.3	9.7	33.3	0.8	8.7	10.1
Nuts	>0.1	3.7	0.1	<0.1	0.1	4.1
Sugar	24.6	1.9	39.4	0.3	0.5	2.3
Cotton	0.1	10.0	0.8	0.3	3.0	10.4
Vegetables	1.6	2.2	2.7	0.3	0.6	2.6
Citrus	0.5	5.3	1.7	0.1	0.2	5.7
Other Fruit	2.9	1.4	4.1	0.1	0.2	1.8
Tobacco	<0.1	2.8	0.1	<0.1	<0.1	3.5
Timber*	0.17	2.0	0.28	0.1	0.1	3.5
Rangeland*	247	0.3	266	5.2	6.1	0.7
Area Insects*	517	0.4	571	1.1	1.3	0.8
TOTAL				11.1	37.6	5.0

* In units indicated in Table 5

TABLE A3

PROJECTION FOR WESTERN EUROPE

Crop Category	Production 1974-76 Av. Prod. 10^9 kg	Production Avg. Gr. Rate %/yr	Production 2000 Prod. 10^9 kg	Treated Area 1975 Area 10^6 kg	Treated Area 2000 Area 10^6 ha	Treated Area Avg. Gr. Rate %/yr
Wheat	50.4	2.4	91.2	0.2	0.5	3.0
Rice	1.1	3.1	2.3	0.1	0.3	3.7
Corn	23.1	5.4	86.1	<0.1	0.1	6.1
Sorghum	0.3	10.9	4.1	<0.1	0.1	12.2
Roots	42.9	-3.5	17.6	0.2	0.1	-2.9
Dry Beans	0.8	-2.6	0.4	0.1	<0.1	-2.0
Soybeans	2.6	1.2	3.5	<0.1	<0.1	1.8
Other Grains	41.8	3.8	106.1	0.5	1.3	4.4
Nuts	0.5	-2.7	0.2	<0.1	<0.1	-1.9
Sugar	82.6	3.2	181.6	<0.1	0.1	3.8
Cotton	0.1	-8.6	<0.1	<0.1	<0.1	-8.8
Vegetables	35.4	-1.0	27.5	0.3	0.3	-0.4
Citrus	2.9	5.1	10.0	<0.1	0.1	5.6
Other Fruit	42.5	2.0	69.7	0.1	0.2	2.6
Tobacco	0.2	3.5	0.6	<0.1	<0.1	4.9
Timber*	1.88	-2.0	1.13	<0.1	<0.1	-1.5
Rangeland*	165	0.5	187	0.2	0.2	1.1
Area Insects*	123	-0.7	103	<0.1	<0.1	-0.3
TOTAL				1.8	3.4	2.4

* In units indicated in Table 5

TABLE A4

PROJECTIONS FOR SOUTH AFRICA

	Production			Treated Area		
Crop Category	1974-76 Av. Prod. 10^9 kg	Avg. Gr. Rate %/yr	2000 Prod. 10^9 kg	1975 Area 10^6 kg	2000 Area 10^6 ha	Avg. Gr. Rate %/yr
Wheat	1.8	6.7	9.2	0.2	0.9	6.7
Rice	<0.1	3.4	<0.1	<0.1	<0.1	3.4
Corn	9.2	4.8	29.7	0.3	0.8	4.8
Sorghum	0.4	3.6	1.1	0.1	0.3	3.6
Roots	0.8	5.2	2.7	0.1	0.3	5.2
Dry Beans	0.1	4.4	0.2	0.1	0.3	5.2
Soybeans	0.1	4.0	0.2	<0.1	<0.1	3.9
Other Grains	0.3	7.0	1.6	0.1	0.4	7.0
Nuts	0.3	2.9	0.7	0.2	0.4	2.9
Sugar	17.5	5.3	63.8	0.2	0.7	5.3
Cotton	0.1	10.2	1.3	0.4	4.0	10.2
Vegetables	1.4	3.1	3.0	0.3	0.6	3.1
Citrus	0.7	2.9	1.5	0.1	0.2	2.9
Other Fruit	2.0	4.7	6.4	0.1	0.3	4.7
Tobacco	<0.1	1.4	<0.1	<0.1	<0.1	1.4
Timber*	2.26	1.2	3.05	0.6	0.9	1.2
Rangeland*	43	-1.4	30	0.9	0.6	-1.4
Area Insects*	96	-0.3	89	0.2	0.2	-0.3
TOTAL				3.7	10.8	4.4

* In units indicated in Table 5

TABLE A5

PROJECTIONS FOR JAPAN

Crop Category	Production 1974-76 Av. Prod. 10^9 kg	Avg. Gr. Rate %/yr	2000 Prod. 10^9 kg	Treated Area 1975 Area 10^6 kg	2000 Area 10^6 ha	Avg. Gr. Rate %/yr
Wheat	0.2	-13.6	<0.1	<0.1	<0.1	-13.6
Rice	16.1	-0.2	15.3	1.2	1.2	-0.2
Corn	<0.1	-15.9	<0.1	<0.1	<0.1	-15.9
Sorghum	-	-	-	-	-	-
Roots	5.3	-5.6	1.2	<0.1	<0.1	-6.0
Dry Beans	0.2	-3.6	0.1	<0.1	<0.1	-4.0
Soybeans	0.1	-2.0	0.1	<0.1	<0.1	-2.0
Other Grains	0.2	-6.0	<0.1	<0.1	<0.1	-6.0
Nuts	0.1	-1.6	0.1	<0.1	<0.1	-1.6
Sugar	4.0	1.1	5.3	<0.1	<0.1	-5.3
Cotton	-	-	-	-	-	-
Vegetables	15.1	1.9	24.1	0.1	0.2	1.9
Citrus	4.3	10.4	51.1	<0.1	0.2	10.3
Other Fruit	2.7	1.1	3.5	<0.1	<0.1	0.9
Tobacco	0.5	0.5	0.3	<0.1	<0.1	0.5
Timber*	1.70	-2.8	0.80	<0.1	<0.1	-3.0
Rangeland*	3.6	-0.3	3.3	<0.1	<0.1	-0.3
Area Insects*	6.0	0	6.0	<0.1	<0.1	0
TOTAL				1.4	1.6	0.4

* In units indicated in Table 5

TABLE A6

PROJECTIONS FOR ISRAEL

	Production			Treated Area		
Crop Category	1974-76 Av. Prod. 10^9 kg	Avg. Gr. Rate %/yr	2000 Prod. 10^9 kg	1975 Area 10^6 kg	2000 Area 10^6 ha	Avg. Gr. Rate %/yr
Wheat	0.2	8.5	1.8	<0.1	0.1	8.6
Rice	-	-	-	-	-	-
Corn	<0.1	7.3	0.1	<0.1	<0.1	7.3
Sorghum	<0.1	-5.2	<0.1	<0.1	<0.1	-6.2
Roots	0.2	3.8	0.4	<0.1	<0.1	3.7
Dry Beans	-	-	-	-	-	-
Soybeans	<0.1	4.0	<0.1	<0.1	<0.1	4.5
Other Grains	<0.1	-6.2	<0.1	<0.1	<0.1	-6.9
Nuts	<0.1	5.6	0.1	<0.1	<0.1	5.7
Sugar	0.2	-0.7	0.2	<0.1	<0.1	-0.7
Cotton	0.1	10.0	1.4	0.3	3.5	10.0
Vegetables	0.7	5.0	2.4	0.1	0.4	5.0
Citrus	1.6	7.3	9.5	0.1	0.9	7.3
Other Fruit	0.3	3.5	0.8	<0.1	<0.1	3.5
Tobacco	-	-	-	-	-	-
Timber*	-	-	-	-	-	-
Rangeland*	0.5	1.4	0.7	<0.1	<0.1	1.4
Area Insects*	1.2	0.8	1.5	<0.1	<0.1	0.8
TOTAL				0.7	5.0	8.5

*In units indicated in Table 5

TABLE A7

PROJECTIONS FOR USSR

Crop Category	Production: 1974-76 Av. Prod. 10^9 kg	Production: Avg. Gr. Rate %/yr	Production: 2000 Prod. 10^9 kg	Treated Area: 1975 Area 10^6 kg	Treated Area: 2000 Area 10^6 ha	Treated Area: Avg. Gr. Rate %/yr
Wheat	82.3	2.1	138.4	9.3	13.1	1.4
Rice	2.0	7.0	10.9	5.4	24.5	6.3
Corn	9.9	-2.3	5.5	0.3	0.2	-3.0
Sorghum	0.2	9.9	2.2	0.1	0.5	9.1
Roots	84.9	0.3	91.5	10.6	9.6	-0.4
Dry Beans	1.3	1.1	1.1	2.9	3.2	0.4
Soybeans	5.9	4.0	15.6	0.9	2.0	3.3
Other Grains	58.9	7.3	342.6	15.7	76.6	6.6
Nuts	0.2	1.5	0.3	0.1	0.2	0.8
Sugar	81.0	2.6	153.8	1.1	1.7	1.9
Cotton	8.7	4.0	23.2	31.8	84.6	4.0
Vegetables	27.0	2.7	52.6	6.1	10.1	2.0
Citrus	0.1	11.9	2.4	<0.1	0.3	11.2
Other Fruit	13.7	6.5	66.2	0.7	3.0	5.8
Tobacco	0.4	5.1	1.3	0.1	0.4	4.4
Timber*	0.42	0.4	1.30	0.1	0.1	-0.3
Rangeland*	186	1.3	257	4.4	5.1	0.6
Area Insects*	604	0.1	619	1.4	1.2	-0.6
TOTAL				91.0	236.4	3.9

* In units indicated in Table 5

TABLE A8

PROJECTIONS FOR EASTERN EUROPE

	Production			Treated Area		
Crop Category	1974-76 Av. Prod. 10^9 kg	Avg. Gr. Rate %/yr	2000 Prod. 10^9 kg	1975 Area 10^6 kg	2000 Area 10^6 ha	Avg. Gr. Rate %/yr
Wheat	26.8	5.1	92.8	0.7	6.2	9.0
Rice	0.2	3.7	0.5	0.1	0.7	7.5
Corn	19.1	4.4	56.2	0.2	1.1	8.2
Sorghum	<0.1	2.7	0.1	<0.1	<0.1	7.1
Roots	66.6	0	66.6	2.0	4.9	3.7
Dry Beans	0.3	0.6	0.3	0.1	0.4	4.3
Soybeans	0.4	10.0	4.80	<0.1	0.4	13.8
Other Grains	15.0	6.4	70.5	1.0	11.1	10.3
Nuts	0.1	-0.9	0.1	<0.1	<0.1	2.6
Sugar	39.5	1.9	63.2	0.1	0.5	5.6
Cotton	0.2	-1.0	0.1	0.1	0.3	2.6
Vegetables	17.6	-1.5	12.0	1.0	1.6	2.1
Citrus	<0.1	5.9	<0.1	<0.1	<0.1	5.9
Other Fruit	9.3	2.3	16.4	0.1	0.5	6.1
Tobacco	0.3	2.5	0.6	<0.1	0.1	6.4
Timber*	3.71	6.1	16.0	0.3	3.3	10.0
Rangeland*	60	0.7	71	0.3	1.0	4.4
Area Insects*	61	-0.2	58	<0.1	0.1	3.5
TOTAL				6.2	32.4	6.8

* In units indicated in Table 5

TABLE A9

PROJECTIONS FOR CUBA

Crop Category	Production: 1974-76 Av. Prod. 10^9 kg	Production: Avg. Gr. Rate %/yr	Production: 2000 Prod. 10^9 kg	Treated Area: 1975 Area 10^6 kg	Treated Area: 2000 Area 10^6 ha	Treated Area: Avg. Gr. Rate %/yr
Wheat	-	-	-	-	-	-
Rice	0.2	10.6	1.9	0.4	4.5	10.6
Corn	0.1	-1.1	0.1	<0.1	<0.1	-1.1
Sorghum	-	-	-	-	-	-
Roots	0.6	1.5	0.9	0.1	0.1	1.5
Dry Beans	0.1	-2.9	<0.1	0.1	0.1	-2.9
Soybeans	-	-	-	-	-	-
Other Grains	-	-	-	-	-	-
Nuts	<0.1	-2.3	<0.1	<0.1	<0.1	-2.3
Sugar	53.4	1.9	85.5	0.6	1.0	1.9
Cotton	<0.1	-6.0	<0.1	<0.1	<0.1	-5.9
Vegetables	0.4	4.4	1.1	0.1	0.2	4.4
Citrus	0.2	5.8	0.8	<0.1	0.1	5.8
Other Fruit	0.4	3.2	0.8	<0.1	<0.1	3.3
Tobacco	<0.1	3.2	0.1	<0.1	<0.1	0.5
Timber*	1.50	-3.3	0.64	0.5	0.2	-3.3
Rangeland*	5.8	-0.7	4.9	0.1	0.1	-0.7
Area Insects*	5.8	3.5	13.7	<0.1	<0.1	3.6
TOTAL				1.9	6.4	4.9

* In units indicated in Table 5

TABLE A10

PROJECTIONS FOR CHINA

Crop Category	Production 1974-76 Av. Prod. 10^9 kg	Avg. Gr. Rate %/yr	2000 Prod. 10^9 kg	Treated Area 1975 Area 10^6 kg	2000 Area 10^6 ha	Avg. Gr. Rate %/yr
Wheat	40.3	5.1	139.9	<0.1	0.1	5.1
Rice	116.0	2.5	215.1	1.2	2.2	2.5
Corn	32.8	3.1	70.3	<0.1	<0.1	3.3
Sorghum	<0.1	18.0	1.3	<0.1	<0.1	18.0
Roots	154.2	2.8	307.6	0.1	0.1	2.8
Dry Beans	6.5	4.5	19.5	0.1	0.2	4.5
Soybeans	16.9	2.3	29.9	<0.1	<0.1	2.1
Other Grains	22.4	2.6	42.6	<0.1	<0.1	2.6
Nuts	3.1	3.2	6.9	<0.1	<0.1	3.1
Sugar	51.5	5.8	211.0	<0.1	<0.1	5.3
Cotton	8.7	6.6	42.9	0.1	0.6	6.6
Vegetables	65.2	2.8	130.1	0.1	0.1	2.8
Citrus	1.3	5.3	4.7	<0.1	<0.1	2.8
Other Fruit	4.3	3.5	10.2	<0.1	<0.1	2.8
Tobacco	1.3	3.8	3.4	<0.1	<0.1	3.7
Timber*	1.20	4.3	3.50	<0.1	<0.1	2.8
Rangeland*	138	0.9	172	<0.1	<0.1	0.9
Area Insects*	342	0.6	397	<0.1	<0.1	0.6
TOTAL				1.5	3.3	3.1

* In units indicated in Table 5

TABLE A11

PROJECTIONS FOR TROPICAL LATIN AMERICA

Crop Category	Production			Treated Area		
	1974-76 Av. Prod. 10^9 kg	Avg. Gr. Rate %/yr	2000 Prod. 10^9 kg	1975 Area 10^6 kg	2000 Area 10^6 ha	Avg. Gr. Rate %/yr
Wheat	2.8	10.7	36.1	<0.1	0.5	10.1
Rice	11.5	3.2	25.3	4.6	8.6	2.6
Corn	20.9	3.7	51.9	0.1	0.2	3.1
Sorghum	1.7	11.4	24.7	0.1	0.9	10.7
Roots	36.7	1.9	58.8	0.7	0.9	1.3
Dry Beans	5.5	-0.1	5.4	1.8	1.5	-0.7
Soybeans	11.9	10.0	129.3	0.3	2.5	9.3
Other Grains	0.4	0.7	0.5	<0.1	<0.1	0.7
Nuts	0.7	-0.6	0.6	0.1	0.1	-1.2
Sugar	177.0	2.6	328.2	0.4	0.6	1.9
Cotton	3.1	2.5	5.9	1.7	2.7	2.0
Vegetables	5.5	2.3	9.8	0.2	0.3	1.7
Citrus	8.6	8.2	62.0	0.2	1.1	7.5
Other Fruit	28.5	3.4	65.7	0.2	0.5	2.8
Tobacco	0.4	2.5	0.8	<0.1	<0.1	1.7
Timber*	0.30	0.9	0.37	<0.1	<0.1	0.3
Rangeland*	123	1.5	179	0.4	0.5	0.9
Area Insects*	310	1.9	496	0.1	0.1	1.3
TOTAL				10.8	21.0	2.7

* In units indicated in Table 5

TABLE A12

PROJECTIONS FOR TEMPERATE LATIN AMERICA

	Production			Treated Area		
Crop Category	1974-76 Av. Prod. 10^9 kg	Avg. Gr. Rate %/yr	2000 Prod. 10^9 kg	1975 Area 10^6 kg	2000 Area 10^6 ha	Avg. Gr. Rate %/yr
Wheat	10.2	0.8	12.4	0.4	0.5	0.8
Rice	1.1	4.1	3.1	1.2	3.2	4.1
Corn	9.2	3.7	22.9	0.1	0.3	3.7
Sorghum	5.6	12.4	103.8	0.6	11.1	12.4
Roots	7.7	1.1	10.1	0.4	0.5	1.1
Dry Beans	0.4	3.3	0.9	0.3	0.8	3.3
Soybeans	1.4	8.1	1.0	0.1	0.6	8.1
Other Grains	2.1	1.0	2.6	0.2	0.3	1.0
Nuts	0.4	-0.5	0.3	0.1	0.1	-0.5
Sugar	28.8	2.7	56.0	0.2	0.3	2.7
Cotton	0.8	0	0.8	1.4	1.1	-1.1
Vegetables	5.0	2.1	8.4	0.4	0.7	2.1
Citrus	2.1	4.0	5.7	0.1	0.3	4.0
Other Fruit	8.1	3.1	17.3	0.2	0.4	3.1
Tobacco	0.2	5.6	0.7	<0.1	0.1	5.6
Timber*	0.16	0.5	0.18	<0.1	0.1	0.5
Rangeland*	207	1.3	286	1.9	2.6	1.3
Area Insects*	258	0.3	278	0.2	0.3	0.3
TOTAL				7.9	23.0	4.4

* In units indicated in Table 5

TABLE A13

PROJECTIONS FOR MEXICO

Crop Category	Production 1974-76 Av. Prod. 10^9 kg	Production Avg. Gr. Rate %/yr	Production 2000 Prod. 10^9 kg	Treated Area 1975 Area 10^6 kg	Treated Area 2000 Area 10^6 ha	Treated Area Avg. Gr. Rate %/yr
Wheat	2.9	4.9	9.9	0.3	0.8	4.9
Rice	0.5	3.5	1.1	1.0	2.3	3.5
Corn	8.4	1.1	11.0	0.2	0.3	1.1
Sorghum	3.1	11.0	42.5	0.7	8.9	11.0
Roots	0.8	4.2	2.3	0.1	0.2	4.2
Dry Beans	1.3	2.5	2.4	2.2	4.1	2.5
Soybeans	1.0	0.7	1.2	0.1	0.1	0.7
Other Grains	0.9	7.0	4.7	0.2	1.0	7.0
Nuts	0.1	-0.8	0.1	<0.1	<0.1	-0.8
Sugar	34.4	2.6	65.3	0.4	0.7	2.6
Cotton	0.8	0	0.8	2.3	2.3	0
Vegetables	2.8	6.5	13.4	0.5	2.3	6.5
Citrus	2.9	6.7	14.4	0.3	1.5	6.7
Other Fruit	3.4	4.2	9.6	0.1	0.4	4.2
Tobacco	0.1	0	0.1	<0.1	<0.1	0
Timber*	0.19	-0.1	0.19	<0.1	<0.1	-0.1
Rangeland*	33	1.9	53	0.6	1.0	1.9
Area Insects*	95	-0.4	86	0.2	0.2	-0.4
TOTAL				9.0	25.9	4.3

* In units indicated in Table 5

TABLE A14

PROJECTIONS FOR NEAR EAST

	Production			Treated Area		
Crop Category	1974-76 Av. Prod. 10^9 kg	Avg. Gr. Rate %/yr	2000 Prod. 10^9 kg	1975 Area 10^6 kg	2000 Area 10^6 ha	Avg. Gr. Rate %/yr
Wheat	39.4	3.1	84.4	0.3	0.8	3.9
Rice	5.3	2.2	9.1	1.1	2.2	3.0
Corn	8.4	2.9	17.1	<0.1	0.1	3.7
Sorghum	1.7	3.0	3.6	<0.1	0.1	3.7
Roots	12.9	2.6	24.4	0.1	0.3	3.3
Dry Beans	1.3	0.9	1.6	0.2	0.3	1.6
Soybeans	8.5	1.6	12.6	0.1	0.2	2.3
Other Grains	18.8	4.5	56.6	0.4	1.3	5.3
Nuts	1.3	3.4	3.1	0.1	0.2	4.1
Sugar	24.6	8.2	176.7	<0.1	0.2	8.9
Cotton	4.1	1.5	6.0	1.1	1.9	2.2
Vegetables	41.3	3.4	95.4	0.7	1.9	4.2
Citrus	7.9	4.2	22.0	0.1	0.3	5.0
Other Fruit	25.9	1.3	35.8	0.1	0.2	2.0
Tobacco	0.5	3.1	1.1	<0.1	<0.1	3.7
Timber*	0.66	0.4	0.73	<0.1	<0.1	1.0
Rangeland*	218	0.9	273	0.4	0.6	1.6
Area Insects*	357	0.2	376	0.1	0.1	1.0
TOTAL				4.8	10.7	3.3

* In units indicated in Table 5

TABLE A15

PROJECTIONS FOR ASIA

Crop Category	Production			Treated Area		
	1974-76 Av. Prod. 10^9 kg	Avg. Gr. Rate %/yr	2000 Prod. 10^9 kg	1975 Area 10^6 kg	2000 Area 10^6 ha	Avg. Gr. Rate %/yr
Wheat	33.7	6.4	159.0	<0.1	0.1	9.1
Rice	156.4	2.5	290.0	1.4	4.9	5.1
Corn	16.3	3.2	35.9	<0.1	<0.1	5.1
Sorghum	10.1	0.8	12.3	<0.1	<0.1	3.2
Roots	46.2	3.6	111.9	<0.1	0.1	6.2
Dry Beans	3.6	3.3	8.1	<0.1	0.1	5.8
Soybeans	5.1	3.1	10.8	<0.1	<0.1	4.9
Other Grains	8.0	2.2	13.8	<0.1	<0.1	4.9
Nuts	7.6	1.6	11.3	<0.1	<0.1	4.2
Sugar	230.3	3.3	518.6	<0.1	<0.1	5.7
Cotton	7.7	0.5	8.7	0.1	0.2	3.0
Vegetables	51.5	2.9	105.2	<0.1	0.2	5.5
Citrus	2.1	2.3	3.6	<0.1	<0.1	4.5
Other Fruit	30.8	2.8	61.4	<0.1	<0.1	5.1
Tobacco	1.7	1.7	2.6	<0.1	<01	4.5
Timber*	1.28	2.7	2.50	<0.1	<0.1	6.6
Rangeland*	336	0.7	401	<0.1	0.1	3.2
Area Insects*	440	0.3	474	<0.1	<0.1	2.3
TOTAL				1.7	5.9	5.0

* In units indicated in Table 5

TABLE A16

PROJECTIONS FOR AFRICA

Crop Category	Production: 1974-76 Av. Prod. 10^9 kg	Production: Avg. Gr. Rate %/yr	Production: 2000 Prod. 10^9 kg	Treated Area: 1975 Area 10^6 kg	Treated Area: 2000 Area 10^6 ha	Treated Area: Avg. Gr. Rate %/yr
Wheat	1.3	2.8	2.7	<0.1	<0.1	2.8
Rice	5.3	3.1	11.3	0.7	1.4	3.1
Corn	12.8	3.5	30.8	<0.1	<0.1	3.4
Sorghum	9.0	5.9	37.6	0.1	0.5	5.9
Roots	71.4	2.0	117.1	0.4	0.7	2.0
Dry Beans	3.5	1.7	5.3	0.4	0.6	1.7
Soybeans	2.1	1.5	3.0	<0.1	<0.1	1.4
Other Grains	18.7	3.0	39.2	0.2	0.5	3.0
Nuts	7.9	0.6	9.2	0.2	0.3	0.6
Sugar	27.7	4.4	81.4	<0.1	0.1	4.3
Cotton	2.0	3.3	4.5	0.3	0.8	3.3
Vegetables	8.5	2.4	15.8	0.1	0.2	2.5
Citrus	1.0	5.7	4.2	<0.1	<0.1	5.4
Other Fruit	19.5	2.6	37.0	<0.1	0.1	2.6
Tobacco	0.4	3.2	0.8	<0.1	<0.1	3.4
Timber*	0.48	1.3	0.66	<0.1	<0.1	1.3
Rangeland*	227	1.4	321	0.3	0.4	1.4
Area Insects*	827	0.2	869	0.1	0.1	0.2
TOTAL				2.9	5.6	2.6

* In units indicated in Table 5

CASE STUDY SELECTION

An important premise in selecting a case-study country was that it should have a reasonably well-developed agricultural sector in order to be considered a significant market for agricultural aircraft. If other necessary agricultural investments (such as adequate irrigation, acceptable soil conditions, high-yielding species, and sufficient knowledge among farmers) have not been made, there is little chance that a high-technology solution would be successfully adopted on other than an emergency basis. Investments in agricultural aircraft must, therefore, be preceded by these other necessary agricultural inputs. The existence of this technical base is reflected by increases in the productivity of the land, i.e., crop yields.

One indicator of agricultural development are the yields of various crops. The stability, or year-to-year variation of yield is affected by climatic conditions (droughts, etc.) and diseases which increase harvesting losses. For preliminary screening of countries, a three-year average of yields for various countries was tabulated. Very low yields indicate lack of basic agricultural inputs necessary for development. Of course, the figures are aggregate -- there may be a very small commercial sector at a high level of efficiency. Another factor in choosing a country was the desirability of the country producing a variety of crops such that some extrapolation of the case-study results could be made to other regions of the world. This effectively eliminated some countries, e.g., Malaysia and the Philippines because they are predominantly rice-producing. For these reasons, production data were compiled along with yield data, as shown in Table A17. The countries in Table A17 are representative of their regions with respect to size, agricultural sector and, in most cases, have a history of ag-aircraft use (Refs. 10, 17, 24). The crops tabulated include the major crops for which ag-airplanes are utilized in the US, and several others occurring predominantly in tropical developing countries.

A smaller set of candidate countries was then chosen from this list. It was decided to select at least one country from each region to assure a good variety. Three primary criteria were employed to make these selections. It was required that relatively high yields be attained for a variety of crops, for the reason given above. The second criterion was a history of ag-airplane fleets, recent deliveries, or contractor operations, resulting in significant ag-aviation activity as a precedent for further expansion. Country size also played an important role in order that the country alone could result in a market for airplanes.

In East Africa, the choice of the Sudan was based on its relatively high yields for a variety of crops. It has the largest airplane fleet in the region and is acknowledged to be a potential "breadbasket" of the world. West Africa has the smallest airplane use of any region, so the choice was

TABLE A17

CROP YIELDS AND PRODUCTION FOR REPRESENTATIVE DEVELOPING COUNTRIES

(Annual Average for 1974-76)

REGION	COUNTRY	COTTON		RICE		WHEAT		CORN		SOYBEANS		SORGHUM		COFFEE		SUGARCANE		BANANAS	
		Yield*	Prod**	Yield	Prod	Yield	Prod	Yield	Prod	Yield	Prod	Yield	Prod	Yield	Prod	Yield	Prod	Yield	Prod
East Africa	Ethiopia	500	53	-	-	867	608	1,451	1,182	-	-	909	774	372	167	171 889	1 147	N/A	65
	Kenya	256	16	5,110	33	1,498	163	1,163	1 453	-	-	-	-	840	73	69 489	1 925	N/A	18[illegible]
	Malagasy (Madagascar)	1,649	27	1,704	1,844	-	-	1,078	126	-	-	548	2	376	86	43 174	1,317	N/A	380
	Mozambique	372	96	1,387	100	1,000	4	564	383	-	-	860	215	714	1	45,441	2,667	N/A	64
	Rhodesia	1,516	120	1,698	5	2,881	87	3,098	1,500	-	-	716	50	-	-	100,683	2,608	N/A	44
	Somalia	321	3	3,013	5	343	1	957	123	-	-	411	119	-	-	74,222	393	N/A	147
	Sudan	1 127	547	1,067	7	1,102	256	593	51	-	-	733	1,843	-	-	83,760	1,388	N/A	81
	Tanzania	556	183	1,495	384	1 030	54	944	1 473	176	1	850	384	504	54	30 306	1 252	N/A	747
	Uganda	199	122	861	16	2 300	15	1,102	525	1,062	6	1,496	517	875	209	63 303	468	N/A	322
	Zaire	351	53	699	202	472	2	643	416	569	2	-	-	316	79	89 439	612	N/A	78
West Africa	Angola	782	61	1,317	22	1 025	13	718	433	-	-	-	-	384	122	43 103	540	N/A	290
	Central African Rep	285	41	910	12	-	-	390	41	-	-	-	-	369	12	-	-	N/A	70
	Gabon	-	-	2,000	2	-	-	1,000	2	-	-	-	-	150	1	1,000	8	N/A	10
	Ghana	603	8	933	68	-	-	1,104	408	-	-	621	131	234	3	27 624	187	N/A	26
	Ivory Coast	1,013	62	1 301	441	-	-	585	109	-	-	665	26	330	257	55,289	398	N/A	191
	Nigeria	276	117	1,286	384	2,111	6	731	1,010	384	67	620	3 590	367	3	51 606	697	N/A	-
	Senegal	1,065	43	1 427	121	-	-	918	46	-	-	-	-	-	-	6 848	17	N/A	4
South Asia	India	482	3,629	1 754	68,018	1,306	24,739	1,056	6,365	733	103	593	9,546	546	88	50 724	142,600	N/A	3 452
	Pakistan	865	1,663	2,260	3,779	1,327	7,979	1,231	753	-	-	603	291	-	-	35,036	23 567	N/A	109
East Asia	Indonesia	418	5	2 605	22,664	-	-	1,063	2,727	753	566	-	-	419	164	83 003	14,669	N/A	3 017
	Malaysia (Peninsula)	-	-	2 971	1,716	-	-	7 998	20	3 167	1	-	-	625	5	41,426	700	N/A	425
	Philippines	-	-	1,715	6 105	-	-	839	2,607	784	6	-	-	883	57	49 427	24 422	N/A	1 357
	Thailand	1,011	42	1 822	14,529	-	-	2 356	2,758	962	124	1,716	217	-	-	50 329	15 644	N/A	1,382
Near East	Algeria	997	1	2,410	2	794	1,713	1 636	6	-	-	1 413	2	-	-	-	-	N/A	-
	Egypt	1,924	1,104	5,258	2,398	3,362	1,959	3 620	2,711	-	-	-	-	-	-	81,437	7 414	N/A	112
	Iran	1 528	493	3,659	1 498	1,012	5,394	1,984	58	1 348	69	1,067	9	-	-	108 353	965	N/A	-
	Iraq	1,331	36	2 500	98	765	1,165	2 088	23	-	-	895	5	-	-	34 042	135	N/A	-
	Libya	-	-	-	-	548	63	1,074	2	-	-	-	-	-	-	-	-	N/A	-
	Morocco	1 198	21	3,845	70	1,015	1,873	875	397	-	-	971	61	-	-	10,735	50	N/A	-
	Saudi Arabia	-	-	-	-	1,729	162	5,833	6	-	-	1,436	200	-	-	-	-	N/A	4
	Turkey	1,939	1,341	4,382	248	1,590	14,137	1,998	1,210	1,580	8	-	-	-	-	-	-	N/A	21
Latin America Tropical	Brazil	727	1,566	1,479	7,860	891	2,616	1,585	16,856	1,660	9,665	2,457	541	488	1,079	45,300	96,997	N/A	7,392
	Colombia	1,449	394	4,313	1,571	1,217	62	1,258	820	1,994	115	2,395	396	610	506	49,838	19,143	N/A	1,035
	Costa Rica	1,600	2	1,626	138	-	-	1,306	77	-	-	1,862	23	992	84	59 659	2,302	N/A	1,210
	El Salvador	2,277	195	3,370	48	-	-	1,823	418	-	-	1,221	157	1,306	193	80 310	2,972	N/A	53
	Guatemala	3,025	295	1,356	26	1,220	48	1,285	679	-	-	1,397	84	530	144	77,131	5,291	N/A	523
	Guyana	-	-	1,908	252	-	-	1,864	4	-	-	-	-	600	1	55,096	3 858	N/A	5
	Honduras	1 615	15	1,425	24	833	1	1,013	332	-	-	826	46	462	52	31,564	1 557	N/A	1 387
	Mexico	2 335	821	2,737	476	3 802	2,980	1,270	8,396	1 799	483	2 716	2,125	565	212	70 335	34,292	N/A	1 217
	Nicaragua	2 174	365	2 692	83	-	-	857	199	-	-	934	57	555	47	66,736	2 396	N/A	310
	Uruguay	1,709	1	4 009	189	1,055	496	1,129	197	1,232	15	1 846	129	-	-	39,051	326	N/A	-
	Venezuela	1,070	74	2,901	312	380	1	1,199	580	-	-	1,480	114	186	51	73 064	5,626	N/A	896
Latin America Temperate	Argentina	998	463	3,719	325	1,532	8,580	2 488	7,818	1,483	559	2,677	5 425	-	-	50,894	15 745	N/A	350
	Chile	-	-	3 058	68	1,442	930	3,185	323	-	-	-	-	-	-	-	-	N/A	-
	Peru	1,697	209	4,373	489	952	136	1,613	589	1,169	1	2,958	26	410	54	161,541	9,043	N/A	-

* kg/hectare

** 1000 tonnes/yr = 10^6 kg/yr

based primarily on existing agriculture. Nigeria was picked due to its significance in this region and its rapid development. The choice of a country in South Asia was clearly between India and Pakistan. Since it was impossible to choose between them on the basis of available information, both countries were retained for further consideration. In East Africa, on the other hand, the countries are predominantly rice producers and it was decided not to include any of them for this reason. Both Latin America and the Near East offered many good candidates for a case-study country. Of the Near East countries, Egypt has relatively high yields, surpassed only by Turkey. The latter was not considered a good candidate, however, due to the predominance of very small farms and a continuing need for better irrigation. Egypt was chosen for its well-developed system of cooperatives and use of double-cropping techniques, offering good possibilities for the future. Tropical Latin America is the biggest user of agricultural airplanes and presented the most difficult choice of countries. One obvious candidate is Mexico, with its great diversity of crops and climate. Much attention has been placed on Mexico's agricultural development. Particularly notable are her successes in commercial farming and her technological advances (Ref. 43). A second country was selected to represent the tropical countries of South America. After some discussion with agricultural specialists, it became apparent that Colombia would be a good choice to study impacts of agricultural aircraft. Colombia produces all the crops for which statistics were gathered in significant quantities, and is oriented towards mechanization of her agricultural sector. Colombia is second to Mexico in its agricultural aircraft fleet, and has been a large market for aircraft of US manufacture in recent years. Finally, the selection of Argentina for the temperate South American region was influenced by its large size and extensive use of ag-aircraft.

At this point, further data were gathered for the eight candidate countries to support the final selection. Table A18 shows basic data for these countries.

The countries vary widely in terms of the share of land area devoted to agriculture, shown as Item (9) in Table A18. India can be seen to be intensely cultivated, while Egypt's share of land under cultivation is very small, consisting of only that which is irrigated. The "other" category indicates land for further expansion of agriculture, keeping in mind that it also consists of mountains and other unusable land. Colombia has the highest share of forest and woodlands, some of which could be made into agricultural land.

Agricultural employment, Item (3), provides a measure of the importance of agriculture in the livelihood of the work force. The labor intensities, Item (15), of Colombia, Mexico, and Argentina are lower than the world average, a possible indication of increased mechanization. The most rapid increases

TABLE A18

BASIC COUNTRY DATA

	Nigeria	Sudan	Mexico	Colombia	Argentina	Egypt	India	Pakistan
Population (1000's)								
(1) 1976 Total Population	64,887	18,850	61,196	26,713	25,719	38,429	628,608	72,859
(2) 1976 Economically Active Pop	25,193	5,922	17,663	7,913	9,805	10,780	245,104	20,167
(3) 1976 % of Econ. Active Pop in Agr.	56.9%	79 0%	39 6%	31 [illegible]%	14 2%	52 0%	66.0%	55 5%
Land Area (1000 Ha)								
(4) Total Area (1975)	92,377	250,581	202,206	113,891	277,689	100,145	328,048	80,394
(5) Land Area	91,077	237,600	197,255	103,870	274,669	99,545	296,608	77,872
(6) Arable Land	22,765F	7,450	26,220	3,620F	24,650F	2,730F	162,500F	19,280F
(7) Perm Crops	985F	45	1,780	1,510F	9,900F	132F	4,700F	170F
(8) Perm. Pasture	20,750F	24,000	67,000	17,350F	143,700F	-	12,550F	5,000F
(9) Agricultural Land ((6) + (7))	23,750F	7,495	28,000	5,130F	34,550F	2,862F	167,200	19,450
(10) % of Land in Agr. ((9)/(5))	26%	3%	14%	5%	13%	3%	56%	25%
(11) Forest and Woodlands	31,069	91,500	71,600	77,190*	60,700F	2	67,400F	2,800F
(12) Other Land	15,508	114,605	30,655	4,200	35,719	96,681	49,458	50,622
Population Density								
(13) Overall Density ((1)/(5))	0.71	0.08	0.31	0 [illegible]6	0 09	0.39	2.12	0.94
(14) Agr. Density ((3)x(2)/(6)+(7)+(8))	0.32	0 15	0 07	0.11	0 01	1.96	0.90	0 46
(15) Agr. Density (not including perm. pasture) ((3)x(2)/(9))	0.60	0 62	0 25	0.48	0 04	1 96	0.97	0 58
Food Production								
(16) 1976 Index of Total Food Production	119	173	158	162	138	144	137	172
(17) 1976 Index of Per Capita Food Production	85	117	104	106	116	105	100	117
Irrigation								
(18) 1975 Area (1000 Ha)	15*	1,500F	4,479	20[illegible]F	1,800	2,855*	32,300F	14,300F
(19) % Agr. Land Irrigated ((18)/(6)+(7)+(8))	.03%	4.8%	4.7%	1 2%	1.0%	99.8%	18.0%	58.5%
Living Standard								
(20) 1974 Per Capita Calories/Day	2,084	2.071	2.725	2,182	3,406	2,634	1,950	2,132
(21) 1974 Per Capita Protein (Grams/day)	46.4	60.5	67.0	47.1	107.3	70.7	48.1	57.5
Mechanization								
(22) 1975 Tractors in Use (1000)	7.5	8.8	140.0	31.5	188 0	21.5	227 7	38.0
(23) Tractors per 1000 Ha of Agr Area ((22)/(8)+(9))	0 17	.28	1.47	1 40	1 05	7 51	1.27	1.55

* = Unofficial figure
F = Forecast

in total per-capita food production, Item (17), since the early 60's have taken place in Sudan and Pakistan, both of moderate agricultural employment density. The extent to which this is related to irrigation is difficult to assess.

In spite of rapid progress in agricultural output in Pakistan, Sudan and India, these countries still find it difficult to feed their populations. As seen in Item (20), only Argentina provides nutritional levels comparable to developed nations, while the remaining countries are considerably behind. From Item (19), it is apparent that Egypt is highly dependent on extensive irrigation to achieve its high outputs. Heavy fertilizer use in Egypt, Colombia and Mexico is also an important factor.

An important indication of the possibilities for implementing agricultural airplanes is the extent to which a developing country has adopted mechanization. One of the results of mechanization is the creation of a supporting infrastructure, such as a skilled labor pool, a fuel and spare parts distribution system, and an improvement in the marketing system. These support roles are particularly important for airplanes, with their high initial cost compared to simple farm equipment. Use of mechanization in farming should lead to lower costs, or at least an awareness of the costs involved. This is particularly true of agricultural airplanes whose high initial cost must be offset by benefits not only due to their greater productivity, but also due to their ability to minimize risk of crop losses and to expand operations.

Use of machinery is usually first undertaken on large farms. Farm size is a particularly important criterion for using agricultural airplanes because of problems in turnaround. Data on farm size are not readily available, although they have been published in previous FAO Yearbooks. Instead, data on tractors was used as an indication of the potential for using ag aircraft. The number of tractors per agricultural area, Item (23), is rather small (except for Egypt), particularly when compared to the United States. The numbers are somewhat distorted by including permanent pastures as part of agricultural area. Although the magnitudes of the tractor fleets, Item (22), are different, the growth rates present an interesting picture. While fleets in India, Pakistan, Sudan, and Nigeria have been growing rapidly, the fleets of Argentina, Mexico, Colombia, and Egypt have been exhibiting a slower and steadier growth, not unlike that of the developed countries. In fact, the number of agricultural machines in use by the US has been declining, partly as a result of their improvements in productivity.

The agricultural aircraft fleet data are shown in Table A19. The data are not as complete as those for surface machinery. Particularly notable is the large number of aircraft delivered to Colombia in recent years. It

TABLE A19

AGRICULTURAL AIRCRAFT FLEETS AND DELIVERIES BY U.S. MANUFACTURERS
FOR CASE-STUDY CANDIDATE COUNTRIES

	Fleet Size	Deliveries by U.S. Manfacturers in 1973-76	Area Treated (10^3 ha)	Utilization (ha/A/C)
Argentina	539	90	5000	9,276
Colombia	280	140	2563	12,322
Mexico	800	6	2750	3,438
Egypt	23	0	1350	58,696
Sudan	50	10	1300	26,000
Nigeria	-	-	-	-
India	50	-	2550	51,000
Pakistan	50	17	2129	42,580

is not clear what portion of the recent deliveries is included in the fleet size, since two different sources were used for this information, so these numbers should be viewed as independent of each other.

The uses of surface machines and ag aircraft are compared in Fig. A5 which shows their numbers per agricultural area, not including permanent pasture. Argentina, Mexico, Colombia, and Egypt have the highest surface machine use of the candidate countries, and are also the leaders in agricultural aircraft use. Of these countries, Colombia and Mexico rely more on airplanes (as measured by airplanes/surface machinery) than the other developing countries in this group. In fact, they even exceed the relative use of aircraft in the three developed countries shown.

Based on the previous discussion, Colombia and Mexico were retained as final candidates for the case study. In order to make the best possible selection, a visit was made to the World Bank in Washington, D.C. to discuss the two countries. An assessment was made of available data sources through contacts at the Bank, at the World Bank Library, and the Washington Embassies.

The final criterion used to make the choice was the likelihood of the country becoming an important market for US-manufactured airplanes. As mentioned earlier, Colombia has been a large purchaser of US-made airplanes in the last three years. Expected expansion of Colombia's agricultural sector suggests a continuation of this trend. The presence of recent import restrictions on US-made aircraft in Mexico has limited the potential of that market. Uncertainty concerning the future environment, therefore, makes it more difficult to project the market in that country.

A variety of crops are grown in Colombia, of which rice, cotton, and bananas seem most amenable to aerial application. Data are available in the Colombian aircraft registry for types, numbers, and areas treated by crops, for individual aircraft. The agricultural sector is very well documented, with detailed information concerning areas, production, fertilizer use and pesticide application, by crop and region, among other data. It was, therefore, recommended that Colombia be chosen as the country for a case study of the ag-aircraft market in developing countries.

USES OF SURFACE MACHINES AND AG AIRCRAFT IN AGRICULTURE

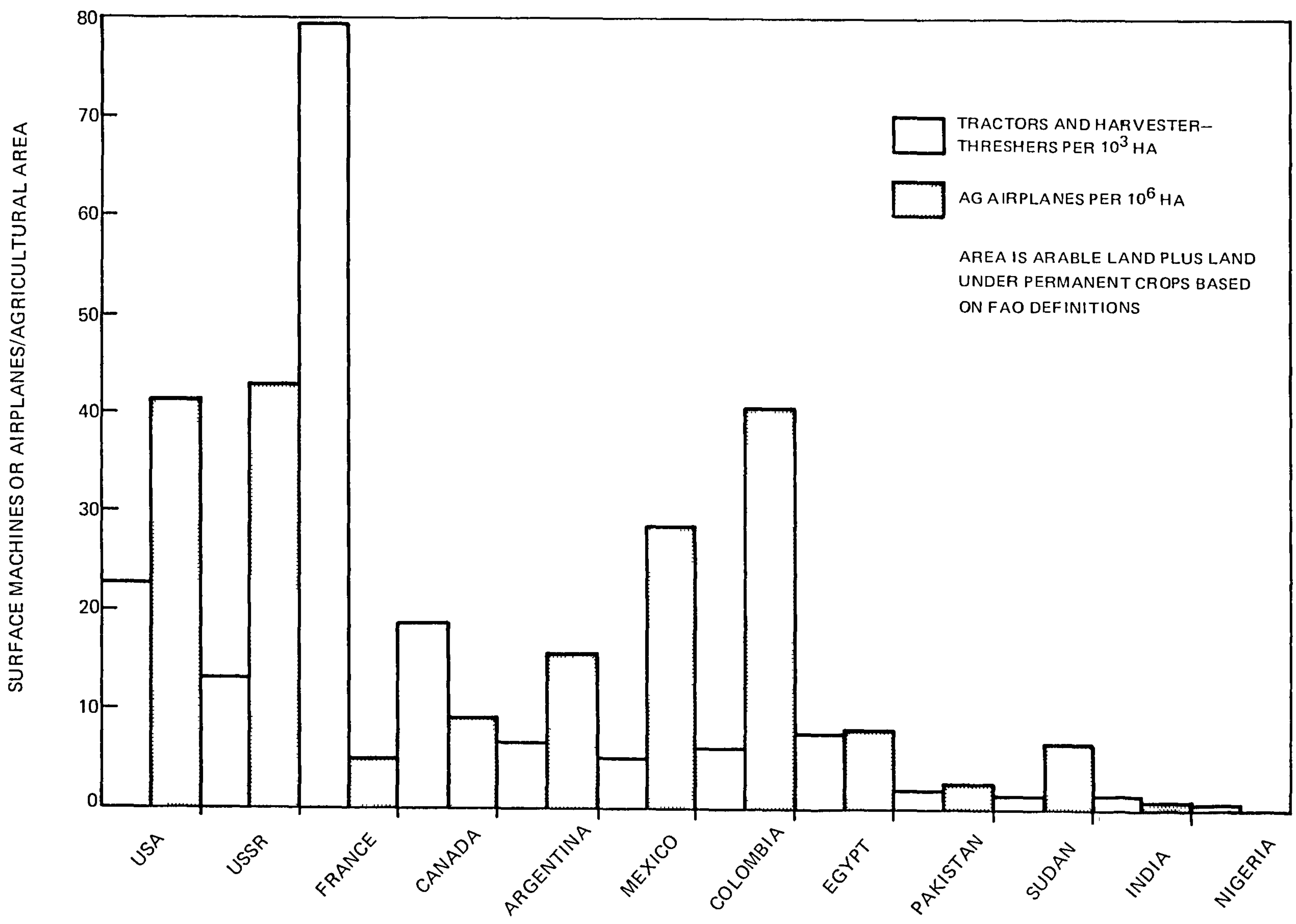


FIG A5

78–07–17–16

BIBLIOGRAPHY

Abel, Martin E.: World Market Conditions for Grains - Prospects and Problems, with Special Reference to the Developing Countries. Minnesota Agricultural Experiment Station, St. Paul, NTIS PB 273 752, 1977.

Actuarial Research Foundation. Agricultural Aviation User Requirements Priorities, NASA Contract NAS1-14758, May 1977.

"Agricultural Aviation and the World's Food Crisis". The World of Agricultural Aviation. June 1975.

Agro-Copterus Ltda. Sales Brochure of Colombian Auto-Gyro for Agricultural Spraying. Apartado Aereo 1789, Cali, Colombia.

American Embassy, Bogota, Colombia. Aviation Equipment (Colombia). DIB-78-07-504, April 1978.

Arthur D. Little, Inc. Outlook for Food and Agribusiness. May 1974.

Austin, James E.: Agribusiness in Latin America. Praeger Special Studies in International Economics and Development, 1974.

"Blight of the Tropics". Newsweek. June 26, 1978.

Brzeska, M.: Five Years at the Research and Development Center of the WSK-Mielec Aircraft Plant. BIIL, Vol. 12, No. 3. (May/June), 1975, pp. 1-3.

CIBA-GEIGY (World Ag-Aviation). The World of Agricultural Aviation. October 1975.

Dalrymple, Dana G.: Technological Change in Agriculture, Effects and Implications for the Developing Nations. Foreign Agricultural Service, USDA in cooperation with Agency for International Development, Washington, D.C., NTIS PB 210 596, April 1969.

Dorner, Peter: The Influence of Land Tenure Institutions on the Economic Development of Agriculture in Less Developed Countries. Wisconsin University, Madison, Land Tenure Center, October 1968.

Emmerson, D. C.: An Economical and Technical Perspective of the Turboprop Engine in Ag-Aviation - Pratt and Whitney of Canada Limited. Canadian Aeronautics and Space Journal. Vol. 24, No. 2, March/April 1978.

"Evolution of an Engine from Drag Racing to Crop Dusting". Machine Design. July 6, 1978.

Grayson, Keith: Agricultural Aircraft - Canada's Opportunity Lost or Deferred? Engineering Research and Development, American Airlines, Inc.

Grzegorzewski, Jerzy. The Aviation Institute's 50th Anniversary: Trends and Developments. BIIL, No. 3-4 (July/August), 1976, pp. 1-7, 12-17.

Grzegorzewski, Jerzy: Show of Polish Agricultural Aircraft. BIIL, No. 5, (September/October), 1975, pp. 1-3.

Guhl, Jean-Michael: M-15 Polish Agricultural Aircraft Produced for the USSR. Air et Cosmos, No. 677 (June 25), 1977, p. 26.

"How Helicopters Can Help Solve the World Food Crisis". Rotor and Wing. December 1975.

International Agricultural Development Service. Agricultural Development Indicators, a Statistical Handbook. IADS, New York, 1978.

Kijanka, T.: Modernization of the An-2R. BIIL, No. 1-2 (January/February), 1976, pp. 1-6, 36.

Lemont, H. E.: Rotary Wing Aerial Applications Systems Study. Bell Helicopters, NASA Contract No. NAS1-15153.

"Low and Slow. A New Generation of Agricultural Aircraft is Helping to Boost Farm Production". United Technologies Bee Hive. Vol. LII, No. 3, Fall 1977.

North, D. M.: Agricultural Aircraft Sales Rise Foreseen. Aviation Week and Space Technology, September 26, 1977, pp. 85-89.

The Polish Aeronautics Industry in the 1976-1980 Five-Year Plan. BIIL, No. 4 (July/August), 1975, pp. 3-4.

Sofiyska Pravda, 16, November 1973, p. 2.

Southwell, P. H.. The Present and Future Technology of Agricultural and Forestry Aviation, with Particular Reference to Canada. Aeronautical Journal. October 1973.

Streeter, Carroll Perry: Colombia: Agricultural Change; The Men and the Methods, A Special Report from the Rockefeller Foundation, 1972.

United Nations Development Program, World Bank. Stemming the River of Darkness. The International Campaign Against River Blindness.

United States Department of Agriculture. Agriculture Statistics 1974. US Government Printing Office, Washington, 1974.

World Bank. Agricultural Credit. Sector Policy Paper, Washington, D.C., May 1975.

World Bank. Agricultural Land Settlement. A World Bank Issues Paper, Washington, D.C., January 1978.

World Bank. The Anatomy of Hunger. World Bank Staff Occasional Papers. No. 23, 1976.

World Bank. Annual Report, 1977.

World Bank Food Insecurity: Magnitude and Remedies. World Bank Staff Working Paper No. 267. July 1977.

World Bank. Health. Sector Policy Paper. March 1975.

World Bank. A Model of Agricultural Production and Trade in Central America. World Bank Staff Working Paper No. 276. April 1978.

World Bank. A Perspective on the Foodgrain Situation in the Poorest Countries. World Bank Staff Working Paper No. 251, Washington, D.C., April 1977.

World Bank. World Bank Atlas. 1977.

World Bank. World Development Report, 1978. Washington, D.C., August 1978.

World Trends in Agricultural and Forestry Aviation. The World of Agricultural Aviation. May 1975.

Yudelman, Montague. Background Paper on the World Food Situation. The World Bank, Agriculture and Rural Development Department, June 6, 1978.

1 Report No	2 Government Accession No	3 Recipient's Catalog No
NASA CR-158937		
4 Title and Subtitle Study of Future World Markets for Agricultural Aircraft		5 Report Date February 1979
		6 Performing Organization Code 3140
7 Author(s) F. W. Gobetz and R. J. Assarabowski		8 Performing Organization Report No R79-912839-24
		10 Work Unit No
9 Performing Organization Name and Address United Technologies Research Center East Hartford, CT 06108		11 Contract or Grant No NAS1-14795
		13 Type of Report and Period Covered Contractor Report May 1978 - February 1979
12 Sponsoring Agency Name and Address National Aeronautics & Space Administration Washington, D.C. 20546		14 Sponsoring Agency Code
15 Supplementary Notes Technical Representative: D. V. Maddalon NASA Langley Research Center Hampton, VA 23665		

16 Abstract

The objectives of this study were to determine the future world market for US-manufactured agricultural aircraft and to identify the technology needs of foreign markets. Special emphasis was placed on the developing-country market, but the developed countries and the communist group were also included in the forecasts. Aircraft needs were projected to the year 2000 by a method which accounted for field size, crop production, treated area, productivity, and attrition of the fleet. A special scenario involving a significant shift toward aerial fertilization was also considered. An operations analysis was conducted to compare the relative application costs of various existing and hypothetical future aircraft. A case study was made of Colombia as an example of a developing country in which aviation is emerging as an important industry.

17 Key Words (Suggested by Author(s))	18 Distribution Statement
Aviation Agriculture Developing Countries, Colombia Aerial Application	Unclassified, Unlimited

19 Security Classif (of this report)	20 Security Classif (of this page)	21 No of Pages	22 Price*
Unclassified	Unclassified		

* For sale by the National Technical Information Service, Springfield, Virginia 22161

DISTRIBUTION LIST

NASA CR-158937
STUDY OF FUTURE WORLD MARKETS
FOR AGRICULTURAL AIRCRAFT
(Contract NAS1-14795)

	No. Copies
National Aeronautics and Space Administration Langley Research Center Hampton, VA 23665	
180A/Report and Manuscript Control Office	1 plus original
249A/Dal V. Maddalon	19
106/D. P. Hearth, Director	1
103A/O. W. Nicks, Deputy Director	1
116/R. E. Bower, Dir. for Aero.	1
249A/C. Driver, ASD	1
249A/D. W. Conner, SAB	1
247/B. J. Holmes	1
118/S. J. Scott	1
National Aeronautics and Space Administration Washington, DC 20546	
R/J. J. Kramer	1
RJ-5/G. G. Kayten	1
RJG-5/H. W. Johnson	1
RHG-5/R. L. Winblade	1
LIB-15/L. F. Hanold	1
National Aeronautics and Space Administration Ames Research Center Moffett Field, CA 94035	
202-3/Library	1
237-3/W. J. Snyder	1
National Aeronautics and Space Administration Dryden Flight Research Center Edwards, CA 93523	
2151/Library	1

	No. Copies
National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, MD 20771	
252/Library	1
National Aeronautics and Space Administration Lyndon B. Johnson Space Center Houston, TX 77058	
JM6/Library	1
National Aeronautics and Space Administration Marshall Space Flight Center Marshall Space Flight Center, AL 35812	
AS61L/Library	1
John F. Kennedy Space Center, NASA Kennedy Space Center, FL 32899	
NWSI-D/Library	1
National Aeronautics and Space Administration Lewis Research Center 21000 Brookpark Road Cleveland, OH 44135	
60-3/Library	1
Jet Propulsion Laboratory 4800 Oak Grove Drive Pasadena, CA 91103	
111-113/Library	1

	No. Copies
Lockheed-Georgia Company Attn: Mr. Roy H. Lange Code 72-79, Zone 12 86 South Cobb Street Marietta, GA 30063	1
Ag. Rotors, Inc. Attn: Mr. Carrol Voss Box 578 Gettysburg, PA 17325	1
Massachusetts Institute of Technology Attn: Mr. Ray Ausrotas Flight Transportation Laboratory Cambridge, MA 02139	1
Mr. Bill Hatfield 12145 Dickinson Nunica, MI 49448	1
Mr. Corwin H. Meyer Chairman of the Board Aircraft Management Associates P. O. Box 207 Menominee, MI 49858	1
Air Transport Association of America Attn: General Clifton F. von Kann 1709 New York Avenue, NW Washington, DC 20006	1
Northrop Corporation Attn: Mr. Winfield H. Arata, Jr. Assistant to the Senior Vice President, Technology 1701 North Fort Myer Dirve, Suite 1208 Arlington, VA 22209	1
Eagle Aircraft Company Attn: Mr. Wayne Mittleider Administrative Offices P. O. Box 4127 Boise, ID 83704	1
Ms. Jenifer Wishart World Bank 1818 H Street, NW Washington, DC 20433	1

	No. Copies
Gellman Research Associates, Inc. Attn: Mr. Aaron J. Gellman President 330 Bent Road Wyncote, PA 19095	1
Operations Research, Inc. Attn: Mr. Patrick J. Steen Transportation Systems Division 1400 Spring Street Silver Spring, MD 20910	1
Diamond Shamrock Corporation Attn: Mr. Pieter W. Vanderlaan Manager, International Product Development Agricultural Chemicals Division 1100 Superior Avenue Cleveland, OH 44114	1
International Civil Aviation Organization Attn: Mr. Jack Vivian Director, Tech. Assistance Bureau P. O. Box 400 1000 Sherbrooke Street West Montreal, Quebec H3A 2R2 Canada	1
Ayres Corporation Attn: Mr. Fred Ayres P. O. Box 3090 Albany, GA 31706	1
Air Rice, Inc. Attn: Mr. Bill Cardiff Katy, TX 77450	1
Pratt and Whitney of Canada, Ltd. Attn: Mr. Derek C. Emmerson P. O. Box 10 Longueuil, Quebec J4K 4X9 Canada	1
Frakes Aviation Attn: Mr. J. F. Frakes Route 3, Box 229B Cleburne, TX 76031	1
National Fertilizer Solutions Assoc. Attn: Mr. Richard Gilliland 1701 West Detweiler Road Peoria, IL 61614	1

	No. Copies
General Aviation Manufacturers Assoc. Attn: Mr. Stanley Green Suite 1215 1025 Connecticut Avenue, NW Washington, DC 20036	1
Econ, Inc. Attn: Dr. George A. Hazelrigg 900 State Road Princeton, NJ 08540	1
National Agricultural Chemical Assoc. Attn: Dr. William Hollis 1155 15th Street, NW Washington, DC 20005	1
USPA Forest Service Attn: Mr. Fred Honing Room 1200, RP-E P. O. Box 2417 Washington, DC 20013	1
Hughes Aircraft Company Attn: Mr. Norman S. Jacobson Centinela and Teale Streets Culver City, CA 90230	1
Bell Helicopter-Textron Attn: Mr. Harold Lemont Box 482 Fort Worth, TX 76101	1
Gulfstream American Aviation Corp. Attn: Mr. George Lundy P. O. Box 2206 Savannah, GA 31402	1
American Jet Industries Attn: Mr. Allen E. Paulson 7701 Woodley Van Nuys, CA 91406	1
Riddell Flying Service West Coast Sales Attn: Mr. David Record P. O. Box 8294 Armona, CA 93202	1
Weatherly Aviation Company, Inc. Attn: Mr. John C. Weatherly 2304 San Felip Road Hollister, CA 95023	1

	No. Copies
Gulfstream American Aviation Corp. Attn: Mr. Micheal G. Rippey P. O. Box 147 Elmira, NY 14902	1
Rutan Aircraft Factory Attn: Mr. Burt Rutan Mojave, CA 93501	1
Agrinautics, Inc. Attn: Mr. George Sanders Box 11045 Las Vegas, NV 89111	1
Air Tractor, Inc. Attn: Mr. Leland Snow P. O. Box 485 Olney, TX 76374	1
Marsh Aviation Attn: Mr. Floyd Stillwell 5060 East Falcon Drive Falcon Field Mesa, AZ 85205	1
Federal Aviation Administration Office of Policy Attn: Dr. Mervin K. Strickler Washington, DC 20591	1
Boeing Vertol Company Attn: Mr. Ken Waters Mail Stop P32-18 P. O. Box 16858 Philadelphia, PA 19142	1
The Fertilizer Institute Attn: Mr. Ed Wheeler 1015 10th Street, NW Washington, DC 20001	1
Central Washington University Attn: Mr. Richard D. Wood Director of Aerospace Studies Ellensburg, WA 98926	1
University of California Attn: Mr. N. B. Akesson Agricultural Engineering Dept. Davis, CA 95616	1

	No. Copies
Schapel Aircraft Company Attn: Mr. Rod Schapel P. O. Box 60039 Reno, NV 89506	1
USDA-ARS Attn: Mr. P. A. Boving 3706 West Nob Hill Blvd. Yakima, WA 98901	1
Delavan Manufacturing Company Attn: Mr. Bob Caviness 3309 S. 95th Street Fort Smith, AR 72903	1
Mississippi State University Attn: Dr. Ernest J. Cross, Jr. Professor and Director - Research Laboratory Mississippi State, MS 39762	1
Spraying Systems Company Attn: Dr. Verne Dietrich North Avenue at Schmale Road Wheaton, IL 60187	1
Dow Chemical Company Agricultural Products Dept. Attn: Dr. Jim B. Grumbles 12700 Park Central Place Suite 600 Dallas, TX 75251	1
Piper Aircraft Corporation Attn: Mr. Charles Diedendorf P. O. Box 1328 Vero Beach, FL 32960	1
National Agricultural Aviation Assoc. Attn: Mr. F. F. Higbee Suite 459, National Press Bldg. Washington, DC 20045	1
Air Enterprises, Inc. Attn: Mr. A. F. Johnson Route 1, Box 13 Magnolia, DE 19962	1

	No. Copies
Lane Aviation, Inc. Attn: Mr. George Lane P. O. Box 432 Rosenburg, TX 77471	1
Cessna Aircraft Company Attn: Mr. Harvey O. Nay Chief Engineer P. O. Box 1521 Wichita, KS 67201	1
Mr. Kenneth Razak 310 Laura Street Wichita, KS 67211	1
The Dow Chemical Company Attn: Mr. C. A. Reimer Agricultural Dept. P. O. Box 1706 Midland, MI 48640	1
University of Kansas Attn: Dr. Jan Roskam Center for Research, Inc. 2291 Irving Hill Road, Campus West Lawrence, KS 66045	1
M & M Air Service Attn: Mr. G. F. Mitchell, Jr. Route 5, Box 890 Beaumont, TX 77706	1
Cessna Aircraft Company Attn: Mr. Dean Noble P. O. Box 1521 Wichita, KS 67201	1
Pingrey Brothers, Inc. Attn: Mr. Everett Pingrey P. O. Box 247 Arbuckle, CA 95912	1
Mid-Continent Aircraft Attn: Mr. Richard Reade Drawer L Hayti, MO 63851	1

	No. Copies
EMAIR Attn: Mr. George A. Roth Harlingen Industrial Airport Hangar 38 Harlingen, TX 78550	1
Delavan Manufacturing Company Attn: Dr. R. W. Tate 811 Fourth Street West Des Noines, IA 50265	1
Union Carbide Corporation Attn: Mr. J. L. Taylor Box 8 McAllen, TX 78501	1

End of Document